S
551.3
N7s
1973

STATE DOCUMENTS

MONTANA STATE LIBRARY

A STUDY OF

EROSION & SEDIMENTATION

Montana Portion, Clarks Fork Yellowstone River Basin

JANUARY 1973

PLEASE RETURN

Prepared for

1973 MONTANA LEGISLATIVE ASSEMBLY

MONTANA STATE LIBRARY

Prepared by

Beartooth Resource Conservation and Development Project

Montana Department of Health and Environmental Sciences

Montana Fish and Game Department

U. S. Soil Conservation Service

Water Resources Division of the Montana Department of Natural Resources and Conservation

Soil Conservation Bureau of the Montana Department of Natural Resources and Conservation

MONTANA STATE LIBRARY
930 East Lyndale Avenue
Helena, Montana 59601

MONTANA STATE LIBRARY
S 551.3 N7s 1973 c.1
A Study of erosion & sedimentation, Mont
3 0864 00007239 0

DATE DUE

MSL MAR 27 '74					
MSL FEB 5 '75					
MSL MAR 19 '75					
MSL DEC 24 '75					
MSL JUN 18 '80					
July 1980					
SEP 26 1990					
9/19					

S/551.3/N7s/1973
Montana. Natural Resources and Conservation, Department of
A study of erosion and sedimentation, Montana portion, Clarks Fork, Yellowstone

S/551.3/N7s/1973
Montana. Natural Resources and Conservation, Department of
A study of erosion and sedimentation, Montana portion, Clarks Fork,
Yellowstone River Basin

STATE DOCUMENTS

MONTANA STATE LIBRARY
930 East Lyndale Avenue
Helena, Montana 59601

MONTANA STATE LIBRARY

A STUDY OF

EROSION & SEDIMENTATION

Montana Portion, Clarks Fork Yellowstone River Basin

JANUARY 1973

Prepared for

1973 MONTANA LEGISLATIVE ASSEMBLY

Prepared by

Beartooth Resource Conservation and Development Project

Montana Department of Health and Environmental Sciences

Montana Fish and Game Department

U. S. Soil Conservation Service

Water Resources Division of the Montana Department of Natural Resources and Conservation

Soil Conservation Bureau of the Montana Department of Natural Resources and Conservation

Digitized by the Internet Archive
in 2013

http://archive.org/details/studyoferosionse00mont

MONTANA DEPARTMENT OF NATURAL RESOURCES AND CONSERVATION

THOMAS L. JUDGE, GOVERNOR
GARY WICKS, DIRECTOR

MEMBERS OF THE BOARD
JOSEPH W. SABOL, CHAIRMAN
DEAN HANSON
RILEY OSTBY
HERBERT HUENNEKENS

449-3647
SAM W. MITCHELL BUILDING
HELENA, MONTANA 59601

January 2, 1973

MEMBERS OF THE 43RD LEGISLATIVE ASSEMBLY

Dear Member:

Silt pollution resulting from poor water use practices has destroyed much of the potential of the Clarks Fork of the Yellowstone River for trout fishing and recreation. There have been tremendous losses of topsoil from farms and ranches and public water systems have been seriously affected.

The 42nd Montana Legislative Assembly, in House Resolution No. 24, directed a study of this problem by the State Board of Health (now Department of Health and Environmental Sciences), the State Fish and Game Department, the Soil Conservation Service, the Beartooth Resource Conservation and Development District, the Montana Water Resources Board (now Water Resources Division of the Department of Natural Resources and Conservation), and the State Soil Conservation Committee (now Soil Conservation Bureau of the Department of Natural Resources and Conservation). The objectives of this study were to delineate the extent of the problem, to determine the origins of the silt pollution, to suggest methods for controlling the sources of erosion causing the pollution, and to formalize the findings in a report for presentation to the 1973 Legislative Assembly.

On behalf of the agencies mentioned hereinabove, I am enclosing a copy of our findings.

Sincerely,

Gary J. Wicks

Gary J. Wicks, Director
Montana State Department of
Natural Resources and Conservation

ACKNOWLEDGEMENTS

This report was prepared by the State Department of Health and Environmental Sciences, State Fish and Game Department, U. S. Department of Agriculture Soil Conservation Service, Water Resources Division of the State Department of Natural Resources and Conservation, and the Beartooth Resource Conservation and Development District with special contribution by the U. S. Department of the Interior Bureau of Reclamation.

Invaluable assistance was also provided by the U. S. Department of the Interior Bureau of Indian Affairs, Bureau of Land Management and Geological Survey; the U. S. Department of Agriculture Forest Service; National Aeronautics and Space Administration; local High Schools and Wyoming Water Planning Staff.

All agencies responsible for completing the study, would like to express their sincere appreciation to all participating parties for their splendid cooperation and assistance.

TABLE OF CONTENTS

INTRODUCTION PAGE

Objectives 1
Conclusions 2
Recommendations for Control 4
Consequences of Control 10

DESCRIPTION OF AREA

Physical Setting 12
Climate 13
Soils 13
Vegetation 15
Land Use 15
Land Ownership 16
Water Quality Classification 17
History 19

METHODOLOGY

Data Gathering 23
Infrared Photography and Thermal Imagery 24
Local Involvement 25

EFFECTS OF EROSION AND SEDIMENT POLLUTION

Recreation, Fish and Wildlife 26
Agriculture 28
Municipal and Industrial Water 29

SOURCES AND CAUSES OF EROSION AND SEDIMENT POLLUTION

Forest and Alpine Area 31
Cropland 32
Rangeland 34
Streams 35
Other Sources of Sediment 38
Additional Pollution Types 39

SURVEYS BY SUB-BASIN

Clarks Fork - Zimmer Creek 40
Line Creek 41
Pat O'Hara, Big Sand Coulee, and NF Cherry - Silver Tip Creeks. . 41
Clarks Fork - Ruby Creek 46
Upper Rock Creek 50
Red Lodge - Rock Creek 51
Elbow - Lower Rock Creek 54
Lower Clarks Fork - East Side 57

TURBIDITY DATA

Description of Sampling Sites 62
Discharge and Turbidity Measurements (table) 63
Tributaries to the Clarks Fork, Yellowstone River
Discharge and Turbidity Measurements (table) 64
Main Stem, Clarks Fork, Yellowstone River

APPENDIX

A. Infrared and Imagery Results - "A Remote Sensing Study of Sediment in the Clarks Fork, Yellowstone River
B. House Resolution No. 24

INTRODUCTION

Objectives

An erosion and sediment pollution study of the Montana portion of the Clarks Fork, Yellowstone River, (hereafter referred to as Clarks Fork) was directed by resolution of the 1971 Montana Legislative Assembly. The resolution, HR 24 (Appendix B), directed the State Board of Health (now Department of Health and Environmental Sciences), the State Fish and Game Department, the Soil Conservation Service, the Beartooth Resource Conservation and Development District, the Montana Water Resources Board (now Water Resources Division of the Department of Natural Resources and Conservation), and the State Soil Conservation Committee (now Soil Conservation Bureau of the Department of Natural Resources and Conservation), to study sediment pollution in the Clarks Fork caused by current water use practices. It also directed a determination of where the sediment pollution is coming from in the drainage, the extent of the problem, and methods for controlling erosion resulting in pollution.

To meet these requirements, an interagency study committee determined that a broad study of the present erosion and sedimentation situation in the basin was necessary. A study of a single aspect of the sediment problem, such as current water use practices, would have little meaning because of the interrelationship of all the factors affecting erosion and sedimentation in the basin.

Conclusions

The erosion and sedimentation problem in the Clarks Fork is very broad and complex. High concentration and extended duration of suspended sediment in the river, have a drastic effect on fishing and recreation and greatly increases the costs of water treatment. Other beneficial water uses are also adversely affected. In addition to these, significant land use problems result from the various types of erosion.

The study committee believes the scope of the problem is great enough to have actually reduced the productive capacity of the land and water resources.

There is a unique combination of factors in this watershed which affect sediment production and make erosion control difficult. The factors are:

High intensity storms

Erosive soils

Steep slopes

Sparse vegetation due to soils and climate

Sediment production in the basin is not entirely a result of these factors. Present and past land and water use practices have increased sediment production. The committee believes the major causes of this increased sediment production are:

Reduced vegetal cover from overgrazing, trampling and improper cropping

Natural tributaries being used as carriers for delivery and return irrigation water

Oil production waste water discharges

Poorly designed and operated irrigation systems including diversions, deliveries and returns

Less significant factors resulting in erosion and sedimentation are:

Soil disturbance activities such as roads, trails, pipelines and land tillage

Stream channel disturbances

Uncapped flowing wells

Destruction of streambank vegetation

Sediment depositions at tributary mouths slowly washing into the river

Improperly located dams

Feedlots

Other rural and urban development

The committee believes the basic underlying reasons behind the problem are:

A lack of understanding or discern for the more fragile areas

Inadequate technology for proper resource management when the area was first settled

A lack of understanding, or indifference to recognize the seriousness of the consequences of erosion among laymen and professionals

A lack of motivation to use funds already available through present programs

A resistance to change and acceptance of modern conservation technology

The inability to acquire capital for implementing controls, and to match federal funds in revenue sharing programs

Economic situations, the returns may not be immediate or pay for the improvements

The fragile setting of the area lends itself to an erosive condition

An indifference to other beneficial water and land uses

The study was neither able to solve nor clarify all questions and misunderstandings in the basin. Stream flows and turbidity measurements taken at the confluence of tributaries to the Clarks Fork did not always correlate. Turbidity values did not always increase when flows increased. Instead they often went down.

The present erosion and sedimentation situation in the Clarks Fork basin provides not only a great opportunity for some problem corrections, but of gaining valuable knowledge toward better management of fragile areas.

Recommendations for Control

There is a need and ample opportunity to accelerate application of existing methods of erosion reduction. Land management, as presently practiced is generally not adequate to correct the problem. There should be more intensive management with more consideration for the fragile setting. In some cases even the most intensive land management practices are not, or will not correct the problem. In those instances land treatments, such as mechanical or structural methods will be needed to get the desired response from land management. It needs to be emphasized that mechanical and structural treatments should always follow or be in conjunction with good land management. There is also an opportunity to apply methods not generally used in this area.

Improved rangeland management will reduce excessive runoff and subsequent sheet, gully and streambank erosion. To accomplish this, management practices such as proper grazing, and animal distribution by fencing and water developments should at all times be implemented prior to other treatments. Another management consideration that may be necessary in

some instances to effect control is the elimination of grazing. If these methods are not successful some mechanical and structural treatments may be necessary. The primary objective of all these activities is to re-establish vegetative cover and condition necessary for erosion reduction.

Erosion control practices recommended on dry cropland include sod waterways, contour stripping, terracing and diversions. These is a need to accelerate the application of these practices. In some cases steeper slopes should be converted to grass.

Irrigated cropland provides some of the best opportunities to reduce sedimentation. Better control of irrigation water would eliminate the need for some wasteways and greatly reduce the quantity of flow through the remainder. Proper application of irrigation water will reduce sediment removal from the fields. Reducing erosion on irrigated lands would benefit the landowner in several ways. Proper irrigation water management usually means less water needed, less nutrient and fertilizer loss, increased crop yields and reduced maintenance costs resulting from erosion and sedimentation.

Specific land management and treatment measures recommended for irrigation are:

Ditch consolidation to reduce unnecessary miles of potential sediment production areas

Encouragement of sprinkler systems for irrigation

Establishment of vegetative buffer strips between streams or eroding areas, and fields and pastures

Encouragement of land leveling and layouts adapted to automated irrigation systems

Better operation, repair and maintenance of water delivery systems; Run down structures and ditches should be repaired

More permanent stream diversion structures to minimize annual maintenance, and to eliminate reconstruction

Elimination, where possible the use of natural tributaries to transport irrigation water or be used as a wasteway; In new systems, natural tributaries should not be used if additional water is supplied by interbasin transfer

More slope stabilizing structures in ditches, and ditch lining

It is also recommended that return flows to live receiving streams should conform to state and federal water quality standards.

Feedlots should be located so that runoff water can be collected before it reaches a live stream. Stock ponds should be located on side slopes and not in drainage ways, except where soil erosion hazards in the watershed are slight. Flowing wells should be capped as per the 1961 Montana Groundwater Code.

There is an opportunity to improve road construction practices and maintenance activities to reduce sedimentation. Drainages should not be filled. Bridges and culverts should be designed to permit unrestricted drainage. Culverts should be placed in the bottom of the fill at the natural slope. Rights-of-way should be designed to permit when possible mechanical reseeding. Top soil, should be replaced, and disturbed areas reseeded with most adapted species as per the 1961 Montana Roadside Re-seeding Law.

Erosion and chemical pollution from oil and gas exploration and production activities can be significantly reduced. Waste water should be reinjected. New and old disturbances from pipelines, roads, well sites and buried oil spills in drainages should be reseeded. Oil from old spills

GOOD CONSERVATION PRACTICES

DITCH LINING

WIND BREAKS

IRRIGATION DROP STRUCTURES

LAND LEVELING

CONTOUR FARMING

MEASURES NEEDED FOR EROSION AND SEDIMENT REDUCTION

REPAIR AND MAINTENANCE
OF IRRIGATION SYSTEMS

DITCH CONSOLIDATION

MINIMIZING IRRIGATION
WASTE WATER

should be collected and disposed of properly. New sumps should be designed to keep oil spills from reaching drainages. Oil sumps that are now in drainages should be removed and the disturbances reseeded. More attention should be given toward avoiding oil spills.

There are many sections of actively eroding streambanks along the Clarks Fork and its major tributaries. In some cases fencing, planting woody species, rock riprap or jetties may be needed. However, these practices should be subsequent to proper land management in order to eliminate and reduce the initial causes of streambank erosion. Riprap, when used, should be placed to conform with the existing stream channel height. The area disturbed should be leveled, topsoiled, and reseeded to accomplish stabilization as quickly as possible. It is recommended that all factors of stream hydrology be considered before proceeding with projects that involve diking, channel realignment, riprap or other encroachment on stream channels or stream banks.

Many gullies and headcuts are active in the basin. Proper grazing management should control most of these. However, occasional stabilization structures may be needed in some instances.

All surface mining activities should conform to the appropriate laws governing reclamation of mined areas.

The committee recommends that all future activities concerning weather modification, if any, be coordinated with land management practices. If future activities are not coordinated, an increase of present erosion rates probably would result with severe consequences.

Technical and financial assistance is available to help landowners install most of these measures. Accelerated technical and financial

assistance is available through the Beartooth RC&D Project and the Great Plains Conservation Program. Higher cost-share rates can be approved for these special practice projects. Low interest rate loans are available from the Farmers Home Administration and the Beartooth RC&D Project.

Certain problems might be best alleviated through use of Public Law 556, the small watershed program. Accelerated technical assistance, cost-sharing and special low interest Farmers Home Administration loans are available in approved P. L. 556 watershed projects.

The Montana Rangeland Resource Program can provide a basis for many control efforts as well as to stimulate interest and activity in erosion control programs.

The committee believes there is a prevailing lack of understanding about erosion and its consequences. Much education is needed on the subject. The committee recommends broader education be emphasized at all levels. Local high schools and youth organizations are excellent opportunities. The local Conservation District, Cooperative Extension Service, and the Beartooth RC&D are ready made tools for implementing education programs.

Higher educational institutions should require more courses on the causes and control of erosion and sedimentation and their effects on all aspects of the environment. Professionals in biological, agricultural and engineering curriculas require a broader perspective than what is presently being provided.

The Montana Stream Preservation Act should be utilized by those agencies covered by the Act. Individuals and other agencies should voluntarily comply with the Act in order to avail themselves of consultation benefits provided for in the Act.

There are laws on record that if more fully enforced could help reduce more erosion and sedimentation in the basin. These include:

1. Montana Water Pollution Control Act (Title 69, Chapter 48, R.C.M. 1947)
2. Conservation Districts Law (Title 76, Chapter 1, R.C.M. 1947)
3. Ground Water Code (Title 89, Chapter 29, R.C.M. 1947)
4. Montana Highway Reseeding Law (Title 32, Chapter 24, R.C.M. 1947)
5. Montana Environmental Policy Act (Title 69, Chapter 65, R.C.M. 1947)
6. Federal Water Pollution Control Act (P. L. 92-500, 86 Stat. 816 33 U.S.C. .... 1972)
7. National Environmental Policy Act (P. L. 91-190, 83 Stat. 42 U.S.C. 4321 1970)

A number of states have recently enacted sediment control laws whereby the land user is liable for sediment produced as a result of improper management or failure to use sediment control measures. The Montana Legislature should consider enactment of such legislation, and provide for enforcement of present laws.

The committee recommends that the legislature consider having additional copies of the report printed for use by local people in the Clarks Fork area and agencies concerned with the problem (printing plates are available).

The committee recommends that the local people initiate an interagency coordinated program for alleviating the basic underlying reasons behind the problem on page 3.

The committee recommends that future water quality studies be conducted over an entire basin and not a split basin.

Consequences of Control

In addition to the obvious benefits that would accrue from correction of sediment and siltation problems in the Clarks Fork Basin, there may be some minor consequences that must be recognized and considered. Problems that could occur include increased cutting of stream banks of the river, degradation of alluvial fans at tributary confluences, increased scour at bridge crossings having constricted channels, and degradation of the stream bed.

In a hypothetical situation the sediment carrying capacity of a stream is normally determined by the velocity of its flow and the characteristics of its channel geometry and configuration. If there is a permanent over or undersupply of sediment in the size range of the bed-material load with respect to the transport capacity of the channel, aggradation or degradation could be expected to occur. Most rivers have had many years to reach a state of equilibrium in which neither of these processes are dominant over an extended period of time. However, should changes occur in the sediment load, flow volume or channel characteristics of the stream, this equilibrium could be destroyed and the stream would seek a different regime to balance the new flow or control conditions. If an oversupply of sediment material is produced by these changes, excess sediment would be deposited in the stream channel (aggradation). If an undersupply of material results from the changes, the streamflow would degrade the channel (banks, bed, fans, etc.) to pick up material in an effort to achieve sediment equilibrium in its flow (degradation). Common causes of nonequilibrium in streams are changes of land use in the watershed, forest fires, construction

of reservoirs, upstream river channel improvements, and climatic factors.

Although a reduction of sediment in the Clarks Fork could cause some increase in degradation of the stream channel, the problems associated with improvement of the flow would not be serious and could be solved with only minor corrective measures.

In summary, benefits from sediment reduction would be much greater than these minor problems.

DESCRIPTION OF AREA

Physical Setting

The Clarks Fork drainage area begins in the high peaks and glaciated plateaus of the rugged Beartooth Mountain Range east of Yellowstone Park. The basin ranges in elevation from 3,300 feet at the mouth of the river, to 12,000 feet on the mountain summits.

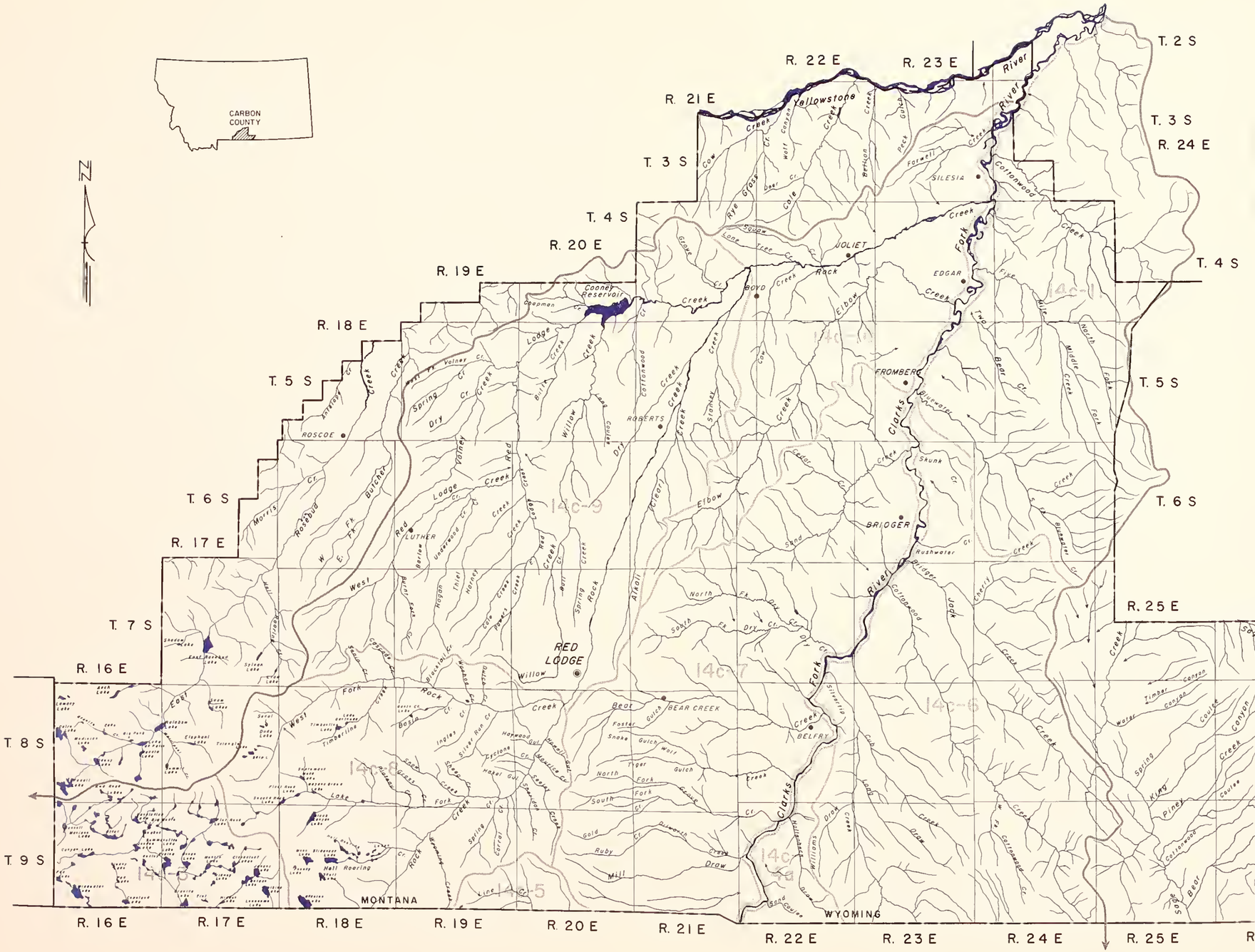
The total area of the Clarks Fork drainage is 1,772,898 acres, of which 976, 328 acres are in Montana. In this report, only the Montana segment is being specifically considered.

The drainage area extends south into Wyoming and includes watersheds of Sunlight Creek, Pat O'Hara Creek, Sand Coulee drainage, Silver Tip Creek, and Cottonwood Creek. Eastward the area extends to the Pryor Mountains, and to the north and west the area includes all the drainages of Rock Creek which empties into the lower Clarks Fork near Silesia.

The sub-basins and their statistical data used in this report are the same as those being used in the Type IV River Basins Survey (water and related land resource study) of the Wind-Bighorn-Clarks Fork River Basin. The Type IV study is under the direction of a Field Advisory Committee headed by the Soil Conservation Service. The sub-basins are as follows:

		Acres
14c-3	Clarks Fork - Zimmer Creek	73,865
*14c-4	Pat O'Hara Creek	797
14c-4a	Big Sand Coulee	13,352
14c-5	Line Creek	11,957
14c-6	N.F. Cherry - Silver Tip Creek	153,942
14c-7	Clarks Fork - Ruby Creek	169,220
14c-8	Upper Rock Creek	120,929
14c-9	Red Lodge - Rock Creek	207,780
14c-10	Elbow - Lower Rock Creek	91,302
14c-11	Lower Clarks Fork - East Side	133,184
	TOTAL	976,328

*not on map



LEGEND

Clarks Fork River Basin

14c-5 SCS Sub Basins

CLARKS FORK RIVER BASIN

DRAINAGE SUB BASINS

MONTANA

SCALE IN MILES

Climate

Temperature and precipitation vary considerably within the Clarks Fork drainage area. In the lower basin area, the average annual temperature is about 45 degrees F. and the average monthly temperatures range from 23 degrees F. in January to 70 degrees F. in July. Extreme temperatures of more than 40 degrees below zero and 100 degrees above have been recorded. In the higher elevations of the study area, the average monthly temperatures range from 17 degrees F. in January to 59 degrees F. in July. Temperature extremes of minus 49 degrees F. and plus 94 degrees F. have been recorded.

Precipitation in the lower basin averages about 13 inches, while in the Beartooth Mountain Range it is nearly 70 inches. There is a rain shadow area in the middle basin where the annual precipitation is as low as 6 inches. In this area the precipitation usually occurs as storms of high intensity and short duration, which have a significant impact on the factors affecting the sedimentation problem.

Soils

Soil Associations:

The soils of the Clarks Fork watershed in Montana have been mapped by the U. S. Soil Conservation Service as part of the National Soil Survey. The area contains nearly 80 soil types that have been consolidated into groups known as soil associations. Each association contains soils that have similar characteristics in terms of productivity, response to treatment, and other factors. Each association is named for the major soil

series in it, however, soils of other series may also be present. Major soils of one association may be present in another, but in a different pattern.

Soil associations are useful to obtain a general idea of soils in an area and to compare soils in different parts of the area. They are not suitable for detailed interpretations on individual tracts of land.

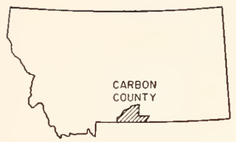
These groupings, or associations, are used in the "Surveys by Sub-basin" section of this report.

Soil Erodibility:

Several different physical features govern the degree of erodibility of soils. The relative proportions of sand, silt and clay particles, organic content, structure and permeability are the most significant features. Knowing these factors, the relative erosion hazard can be interpreted.

Soils with an optimum mixture of particle sizes (well graded) have a high resistance to erosion because they have cohesive and intergranular strength. Loose granular and fine grained soils are highly erodible, particularly on steep slopes. Clay soils vary in erodibility according to the cohesive strengths of the different clays. Some clays and silty clays are highly erosive because they contain expansive minerals that slake during wet and dry cycles. Thus, two different clay loam soils may vary greatly in degree of erodibility.

For purposes of this report the soils have been grouped into three categories according to their erodibility. These three categories are slight, moderate and severe and are described on the map entitled "Soil Erosion Hazards."



LEGEND

Slight Erosive Areas

Soils of this group are nearly level to strongly sloping. They are generally deep on the nearly level fans and terraces and shallow to very shallow over hard rock on the strongly sloping uplands. These soils will not yield large amounts of sediment to the streams under normal use.

Moderate Erosive Areas

Soils of this group occur on gentle to steep slopes. Soils are generally moderately deep to deep on the gentle or moderately sloping fans and footslopes and shallow to gravel or rock on steep terrace edges. They are subject to moderate erosion during hard rains and yield a moderate quantity of sediments to the streams under normal use.

Severe Erosive Areas

Soils of this group occur on nearly level to very steep slopes. The deeper soil areas are in alluvial valleys and flood plains that are subject to streambank and gully erosion. Shallow to very shallow soils occur on steep broken uplands with shale and sandstone outcrop. They are unstable during heavy rains and contribute large volumes of sediment to streams.

CLARKS FORK RIVER BASIN

SOIL EROSION HAZARDS

MONTANA

5 0 5 10

SCALE IN MILES

Vegetation

Vegetation is very diverse due to great variations in altitude and climate throughout the basin. Extremes range from desert type salt bush to alpine tundra. Bunch grasses and sagebrush are the dominate types.

Except in the Rock Creek sub-basin and mountainous portions, vegetation is considered relatively sparse, especially in the rain shadow area.

For more description see section entitled, "Surveys by Sub-basin."

Land Use

Agriculture is the primary land use. Hay is the major crop in the western portion (Rock Creek drainage) while row crops are more extensive in the main stem valley of the Clarks Fork. The main stem valley offers more cropping choices than the Rock Creek drainage area, primarily because of its longer growing season.

There is nearly as much dry cropland (75,492 acres) in the basin as irrigated, (88,628 acres). The variety of crops grown on dryland is limited. Primary dryland crops are wheat and barley.

Rangeland, the dominate land type, occupies 459,513 acres. The productive capacity of rangeland is limited by low rainfall in much of the basin.

There are some popular recreation areas in the basin. The Beartooth Highway passes through the upper reaches of the basin. This road offers access to many high mountain trout lakes which can be reached by either foot or horseback.

Popular fishing streams are the Clarks Fork above Belfry, Rock Creek above Roberts, Clear Creek, Willow Creek, Red Lodge Creek, West Fork and Lake Fork of Rock Creek and Bluewater Creek.

Cooney Reservoir is the most popular boating, fishing, and swimming lake in the basin partially because of its proximity to Billings.

There is considerable oil and gas production in the basin. Elk Basin Oil Field in upper Silver Tip drainage is the largest. A smaller field is also located in the North Fork of Dry Creek.

Land use acreages by types are as follows:

	Acres	Percent
Dry Cropland	75,492	8
Irrigated Cropland	88,628	9
Rangeland	459,513	46
Woodland	105,005	11
Alpine	54,840	6

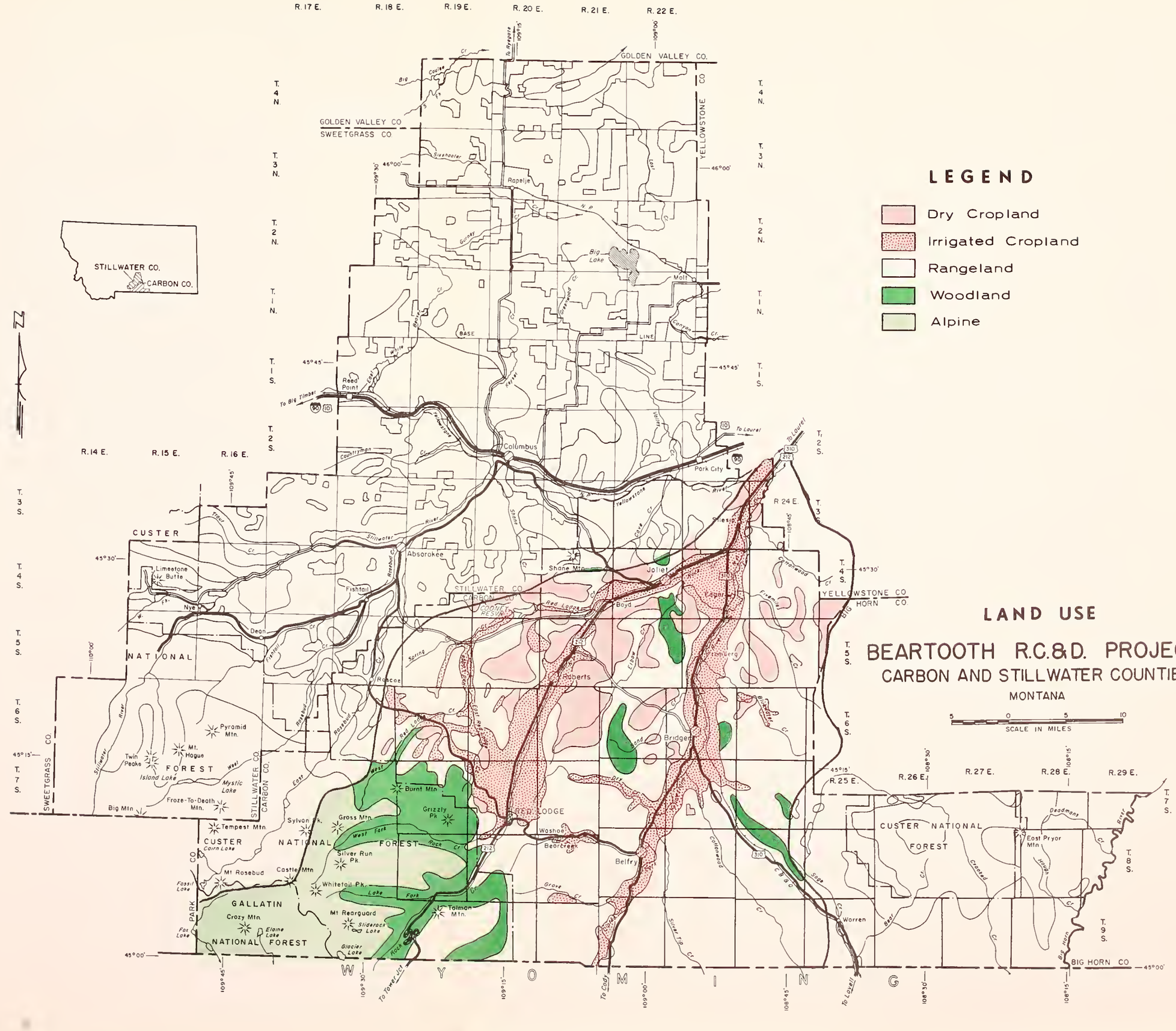
Other uses not delineated on the map are:

Urban and Built-up	11,342	1
Brush	171,977	18
Water	9,531	1
TOTAL	976,328	100%

Land Ownership

Farmers and ranchers are the largest landowners in the basin. The United States is the next largest landowner with management responsibility divided between the Forest Service and the Bureau of Land Management. The State of Montana owns four percent of the land in the basin.

Land ownership, by acreages and percentages, are shown on the following page:


R. 17 E.
R. 18 E.
R. 19 E.
R. 20 E.
R. 21 E.
R. 22 E.
GOLDEN VALLEY CO.
GOLDEN VALLEY CO
SWEETGRASS CO
YELLOWSTONE CO
T. 4 N.
T. 3 N.
T. 2 N.
T. 1 N.
T. 1 S.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
45°00'
45°45'
46°00'
109°45'
110°00'
Big Coulee Cr.
Sixshooter
Rapelje
Gurney
Big Lake
Molt
Canyon Cr.
Greenwood Cr.
Reed Point
To Big Timber
Columbus
Countryman Cr.
Yellowstone River
Absarokee
Shane Mtn.
Joliet
Park City
To Laurel
Silesia
Fishtail
Nye
Dean
Limestone Butte
Rosebud Cr.
Stillwater River
Boyd
Red Lodge
Roberts
Rosebud
Spring Cr.
Pryamid Mtn.
Twin Peaks
Mt. Hague
Island Lake
Mystic Lake
Froze-To-Death Mtn.
Big Mtn.
Tempest Mtn.
Sylvan Pk.
Gross Mtn.
Burnt Mtn.
Grizzly Pk.
Silver Run Pk.
Castle Mtn.
Whitetail Pk.
Mt Rosebud
Fossil Lake
Crazy Mtn.
Elaine Lake
Fox Lake
Mt Rearguard
Sliderock Lake
Glacier Lake
Tolman Mtn.
Red Lodge Cr.
Rock Cr.
Grove Cr.
Bridger
Washoe
Beartooth
Belfry
Worren
Silver Tip Cr.
Clarks Fork Yellowstone
To Tower Jct
To Cody
To Lovell
WYOMING
STILLWATER CO.
CARBON CO.
SWEETGRASS CO.
CUSTER
PARK
BIG HORN CO.
NATIONAL FOREST
Cairn Lake
R. 14 E.
R. 15 E.
R. 16 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.
CUSTER NATIONAL FOREST
East Pryor Mtn.
Deadmans Basin
Crooked Cr.
Big Horn River
LEGEND
Dry Cropland
Irrigated Cropland
Rangeland
Woodland
Alpine
LAND USE
BEARTOOTH R.C.&D. PROJECT
CARBON AND STILLWATER COUNTIES
MONTANA
5 0 5 10
SCALE IN MILES

LAND OWNERSHIP MAP

LEGEND

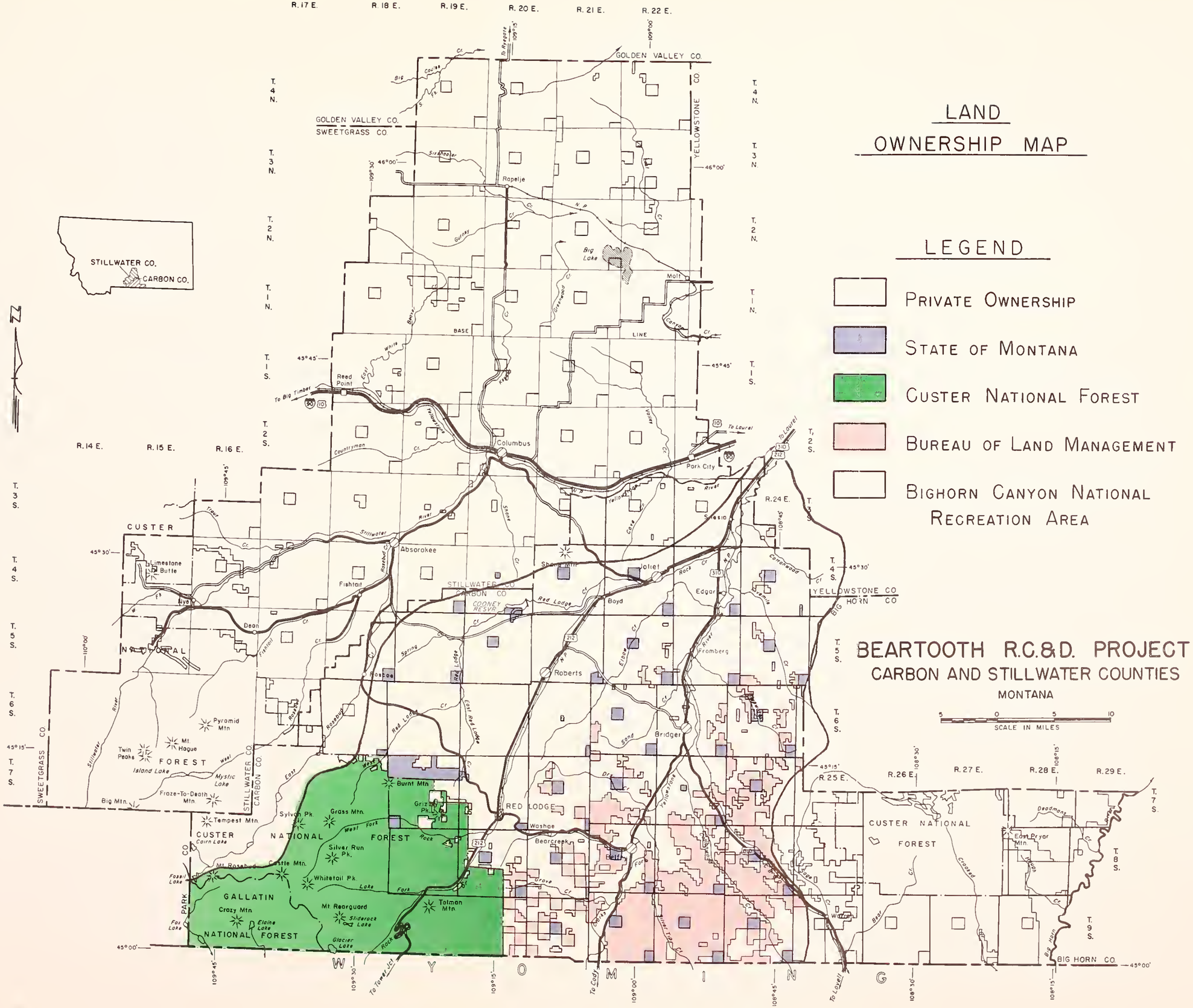
- PRIVATE OWNERSHIP
- STATE OF MONTANA
- CUSTER NATIONAL FOREST
- BUREAU OF LAND MANAGEMENT
- BIGHORN CANYON NATIONAL RECREATION AREA

BEARTOOTH R.C.&D. PROJECT

CARBON AND STILLWATER COUNTIES

MONTANA

SCALE IN MILES 5 0 5 10


STILLWATER CO.
CARBON CO.
N
R.17 E.
R.18 E.
R.19 E.
R.20 E.
R.21 E.
R.22 E.
R.14 E.
R.15 E.
R.16 E.
R.24 E.
R.25 E.
R.26 E.
R.27 E.
R.28 E.
R.29 E.
T. 4 N.
T. 3 N.
T. 2 N.
T. 1 N.
T. 1 S.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
GOLDEN VALLEY CO.
SWEETGRASS CO.
YELLOWSTONE CO.
BIG HORN CO.
STILLWATER CO.
CARBON CO.
SWEETGRASS CO.
BASE LINE
CUSTER
NATIONAL FOREST
GALLATIN
NATIONAL FOREST
CUSTER NATIONAL FOREST
Rapelje
Big Lake
Molt
Reed Point
Columbus
Park City
Laurel
Absorokee
Limestone Butte
Fishtail
Dean
Pyramid Mtn.
Mt. Hague
Twin Peaks
Island Lake
Mystic Lake
Fraze-To-Death Mtn.
Big Mtn.
Tempest Mtn.
Cairn Lake
Mt. Rosebud
Fossil Lake
Fat Lake
Crazy Mtn.
Elaine Lake
Mt. Rearguard
Slideock Lake
Glacier Lake
Tolman Mtn.
Whitetail Pk.
Silver Run Pk.
Castle Mtn.
Sylvan Pk.
Grass Mtn.
Grizzly Pk.
Burnt Mtn.
Sheep Mtn.
Joliet
Boyd
Edgar
Fromberg
Roberts
Bridger
Red Lodge
Washoe
Bearcreek
Belfry
Roscoe
Rosebud
Silesia
Joliet
Deadmans Basin
East Pryor Mtn.
To Big Timber
To Laurel
To Cody
To Lovell
WYOMING
Stillwater River
Yellowstone River
Rosebud Cr.
Red Lodge Cr.
Clarks Fork Yellowstone
Big Coulee Cr.
Big Timber Cr.
Countryman Cr.
Gurley Cr.
Garfield Cr.
Canyon Cr.
Sand Cr.
Dry Cr.
Willow Cr.
Silver Tip Cr.
Coyote Cr.
Bear Cr.
Big Horn River
Deadmans Basin
Crooked Cr.
Rock Cr.
Grove Cr.
Elbow Cr.
Catchwood Cr.
Sarpy Cr.
Spring Cr.
Fishtail Cr.
Limestone Cr.
Dean Cr.
Red Lodge Cr.
Cooney Resv.
Absorokee Cr.
Rosebud Cr.
Stillwater River
Yellowstone River
Rock

Montana Section	Acres	Percent
Private Ownership	594,137	61%
State of Montana	36,000	4%
Forest Service	219,247	22%
Bureau of Land Management	126,944	13%
TOTAL	976,328	100%

Water Quality Classification

The Federal Water Quality Act of 1965 provided that all states will classify their waters according to their beneficial uses and adopt water quality standards which would maintain or enhance water quality for those uses. Montana was fortunate in that such a system was already in existence and needed only upgrading and refinement to meet the provisions of the 1965 Act. The updated classification system was adopted by the Montana Water Pollution Control Council on October 5, 1967, and has subsequently been approved by the Environmental Protection Agency.

The classification for the Clarks Fork River Drainage in Montana upstream from Jack Creek near Bridger is B-D_1. Jack Creek and all of the tributaries of the Clarks Fork below Jack Creek are also classified as B-D_1. One exception is the West Fork of Rock Creek Drainage above the Red Lodge water supply intake which is classified higher, as A-Open-D_1. Downstream from the mouth of Jack Creek, the main stem of the Clarks Fork is classified B-D_2.

Briefly, the B-D_1 classification stipulates that the quality of water shall be maintained to allow for: a) its use as a domestic and municipal water supply after adequate treatment; b) swimming and recreation, and; c) the growth and propagation of salmonoid fishes (trout,

essentially) and associated aquatic life. This quality of water would then also be adequate for the perpetuation of other aquatic life and wildlife associated with water and agricultural and industrial water supplies.

The $B\text{-}D_2$ use classification is similar to $B\text{-}D_1$. It differs only in that water quality need be maintained for "marginal" propagation of salmonoid fishes. In other words, salmonoids must be able to live and grow in the stream, but optimum natural reproduction is not expected.

The water quality criteria, which must be maintained to insure that the above beneficial uses will be protected, include limits for temperature, turbidity, sediment, and other toxic and deleterious substances. These criteria are associated with erosion and subsequent water pollution of the Clarks Fork.

There are other criteria but these are not included in this discussion. Very briefly, in the stream sections classified as $B\text{-}D_1$, temperature may be increased above "natural" by two degrees Fahrenheit when stream temperature is under 67 degrees and by only one-half degree when temperatures are 67 or higher, as a total increase of the combined discharges to the stream. The concept of "piggy-backing", or of each discharge adding two degrees, is not allowed. This is also true with other criteria.

Turbidity may not be increased more than five Jackson Turbidity Units over that which occurs as "natural." Toxic substances and sediment may be discharged only to the extent that they will not adversely effect beneficial uses.

The $B\text{-}D_2$ criteria are essentially identical, with the exception that turbidity may be increased by ten JTU's.

For a more detailed discussion the reader is advised to request a copy of "Montana Water Quality Criteria and Stream Classification" from the Montana Department of Health and Environmental Sciences.

History

Archaeological studies of the area indicate that sediment deposition has occurred for over nine thousand years. Artifacts recovered from various strata evidence many periods of prehistoric occupation.

The first record of non-Indian entry into the area was made in 1743 when Chevalier de la Verendrye passed through this Indian territory in search of a route to the Pacific. On July 24, 1806, Captain Clark of the Lewis and Clark Expedition described in his diary that the water at the mouth of the river is, "a light muddy color and much colder than that of the Yellowstone." In years to follow the area was traversed by such historic figures as John Colter, Jim Bridger, John Bozeman and others.

A major influence on sedimentation occurred during the early settlement period. Large numbers of sheep and cattle were grazed indiscriminately until the severe winter of 1886-87. During that winter thousands of livestock died.

More intensive land uses, such as oil and gas exploration, mining, farming, roads, irrigation, transfer of water from one watershed to another, and other activities have noticeably increased sediment production. These subjects will be discussed in more detail later in this report.

Many groups or agencies have made studies of sedimentation and related problems that effect water quality.

The U. S. Bureau of Reclamation recently completed the Shoshone Irrigation Waste Water Study.

The Carbon Conservation District, organized in 1948, recognized the need to assist landowners in control of water erosion and improvement of vegetative condition.

The U. S. Geological Survey has been measuring stream flows on certain segments of the Clarks Fork River since shortly after the turn of the century. The Fish & Game Department contracted with the U.S.G.S. to measure sediment on Bluewater Creek from 1960 to 1970.

In 1966 the U.S.G.S. started water chemical analysis near Belfry. Since July 1969, chemical quality samples have been taken from the Clarks Fork River near Laurel in cooperation with the Environmental Protection Agency and the Health Department. An inventory of the suspended sediment loads of the river near Edgar was commenced by the same agencies in July 1972.

Chemical quality and sediment has been measured on Silver Tip Creek since October 1968.

The Montana Fish & Game Department, recognizing the adverse effect of sedimentation on fisheries, has been active in making investigations along the river. Their Bluewater Sediment Study involving ditch lining, pipelines, fencing and other bank stabilization procedures, conducted in cooperation with private landowners and federal agencies, significantly reduced the amount of sediment from that area. The fishery showed substantial improvement as a result.

Recently the high schools at Joliet and Roberts have conducted classes in water quality and have monitored water quality in various

areas of the drainage.

The Beartooth RC&D Project has presented new opportunities for accelerated planning and problem solving by involvement of local people and State and Federal agencies. The RC&D Program Committee has also requested acceleration of the Type IV River Basin Study and other project proposals relating to the sedimentation problem.

More recent reports pertaining to the area are:

1. "Water Resources Survey of Carbon County, Montana," Montana Water Resources Board, 1966.

2. "Groundwater Inventory," Carbon County, Montana Water Resources Board, 1969.

3. "U.S. Department of the Interior, Geological Survey, Sediment Investigations in the Big Sand Coulee Basin, Wyoming and Montana," Open File Report, U.S. Geological Survey, 1969.

4. "Land Use Planning for the Red Lodge Unit," Billings District, Bureau of Land Management, 1972.

5. "Management Considerations -- Absaroka and Beartooth Primitive Areas," U.S. Forest Service, 1972.

6. "Environmental Impact Summary, Elk Basin Oilfield," Billings District, Bureau of Land Management, 1972.

7. "Environmental Considerations of the Highway Construction in the Clarks Fork District," Shoshone National Forest, U.S. Forest Service, 1972.

8. "A Remote Sensing Study of Sediment in the Clarks Fork, Yellowstone River," Region 6, Bureau of Reclamation, 1972.

9. Bluewater Sediment Study, Progress Reports, Montana Fish and Game, 1960-1969.

Programs and studies underway are:

1. Wind - Bighorn-Clarks Fork Type IV River Basin Study, U.S. Department of Agriculture.

2. Montana Rangeland Resource Program, Montana Department of Natural Resources and Conservation.

3. Cyclone Bar Watershed Investigation, Soil Conservation Service, Wyoming State Office.

4. Elbow Creek Watershed Investigation, Soil Conservation Service, Montana State Office.

METHODOLOGY

Data Gathering

Turbidity Sampling Task Force:

The task force was headed by the supervisor of the Billings Branch Office of the Department of Health and Environmental Sciences.

Due to limited funds and the short time allowed for preparing and compiling data for this report, the committee decided the sampling parameter would have to be turbidity rather than sediment determinations. Determining total sediment is considerably more time consuming and expensive than turbidity determinations.

Turbidity samples were collected at 17 sites on the Clarks Fork and various tributaries. From September 1971 to March 1972, samples were collected monthly. From April to September 1972 samples were collected twice monthly. More frequent sampling was not feasible because of limited time and expense.

When possible, stream flow estimates were made during the field sampling trips. Data from stream gauges maintained by the U.S. Geological Survey were provided to the task force when available.

Turbidity is an expression of the optic property of water. Suspended matter causes light to be scattered and absorbed rather than transmitted through the water. Amounts are expressed as Jackson Turbidity Units. All tests were made on a Hach Model 2100 turbidimeter, located in the water quality laboratory of the Billings Branch Office. Description of the sites and results of the measurements are presented in the "Turbidity Data" section.

Reconnaissance Surveys Task Force:

This task force, headed by the Beartooth Resource Conservation and Development project coordinator, made field observations to determine the present erosion situation in the basin, and the cause and extent of the sedimentation problem. In addition to field work done on the ground the use of aircraft proved to be very helpful in gathering data, familiarizing study participants with the area and maintaining consistancy in the study.

To facilitate the study effort and more accurately assess the various erosion situations, the basin was divided into eight study units. Each unit (sub-basin) is discussed with respect to its specific erosion situation.

Sources of erosion and deposition were categorized by surface features, such as land type or use, rather than by erosion type. All known information and influencing factors were then evaluated to determine the causes associated with each source. Influencing factors were topography, geology, soils, vegetation, climate, and land and water use practices.

Sources and causes are discussed in general rather than by specific occurrence, because it was not within the capability of this study to identify each occurrence of erosion and sedimentation, and determine its exact cause.

Infrared Photography and Thermal Imagery

In addition to the previously mentioned programs for studying erosion

and sediment problems in the Clarks Fork of the Yellowstone River, aerial infrared photography and thermal imagery were also used to locate sources of sediment and show the relative magnitude of sediment movements in the river. The Bureau of Reclamation conducted this part of the study under a contract with Colorado State University. A detailed description and results of that program are included in Appendix A.

Local Involvement

In addition to the Beartooth RC&D Project members, many groups and individuals assisted in the study. Valuable guidance and assistance was given by Carbon County officials, the Carbon Conservation District, the Carbon County Development Council, local high schools, ditch companies and numerous individuals who participated in the development meetings and in the monitoring activities.

Special meetings were conducted to inform people and to obtain recommendations pertaining to the program, including a meeting with irrigation company officials. Stream monitoring assistance was arranged through a meeting with science teachers in the schools of the area.

EFFECTS OF EROSION AND SEDIMENT POLLUTION

Recreation, Fish & Wildlife

Reports from local residents indicate that trout fishing in the Clarks Fork was good in the Fromberg area as late as 1924. In addition to trout, whitefish, ling and sauger were also being caught. The first goldeye was seen about 1925. Trout were readily caught at the mouth of Bluewater Creek in the Clarks Fork as late as 1936.

Sediment in the Clarks Fork seemed to get worse after the mid-1930's, with adverse affects evidenced on the sport fishery. Currently, fishing for trout and whitefish ends for the most part a short distance below Belfry. Even the portion from Belfry to the Montana line is not considered a good quality fishery.

Sediment is the main problem to the fishery. It is imperative that a constant flow of water be maintained through the gravel where eggs have been deposited. This flow supplies oxygen to the living egg and removes waste products that otherwise accumulate. Sediment fills the openings in the gravel, thereby reducing or eliminating this flow resulting in egg mortalities.

A good food supply is also necessary to sustain a sport fishery. A basic need for the food production chain is sunlight, which microscopic plant forms require. These plants begin the cycle of nutrient conversion to higher forms of life, such as aquatic insects and fish. Sediment destroys this needed cycle by cutting off light, and the basic production of the stream is lost.

Aquatic insects are the basic fish food organism. There is a constant drift of these insect from upstream clean water areas or tributaries. Sediment prevents insect populations from becoming established by eliminating their food supply and destroying their capability to obtain oxygen, either by the erosive action on delicate gill tissues or by plugging respiratory organs. The physical effect of sediment filling in areas around and under rocks destroys insect habitat and precludes the establishment of a diverse aquatic insect population.

An additional problem, created by sediment, is an increase in water temperature. The solid sediment particles in the stream absorb heat from the sun, which in turn raise water temperature. Any source of sediment laden flows bring this increased temperature into the receiving stream. In addition, water is also warmed as it flows over irrigated fields. This combination of sources of increased temperature has a profound adverse effect on the sport fishery potential of the Clarks Fork.

The result of higher water temperatures and increased sediment has been a change in the types and numbers of fish found in the Clarks Fork. Numbers of game fish have been reduced and these fish have been replaced by rough fish. This comes as a result, not only of reducing the quality of habitat for game fish but of also creating a better habitat for nonsport species.

Trout can tolerate moderate amounts of suspended sediment, but only for short periods. If the duration is extended, trout populations will be severely affected.

Streambank vegetation provides needed shade and is a critical factor in cooling stream temperatures. This vegetation also provides cover for

large trout, as well as habitat for birds and big game. Practices which contribute to sediment pollution in the Clarks Fork also have adverse affects on wildlife habitat and populations.

From an aesthetic standpoint, the potential use of the stream for recreation is damaged by sediment pollution. A sediment polluted stream is aesthetically offensive.

Stream floating is becoming more popular. Given a choice such activities take place in the more aesthetically pleasant surroundings. Development, for recreational uses, is rapidly taking place on numerous Montana streams. If the Clarks Fork were devoid of its additional sediment load, much more interest in terms of both public and private development probably would result. Much of this interest is directly related to the aesthetics of the river system.

Turbid water also increases danger to floaters because hazards in the stream are not so visible.

Agriculture

Agricultural interests also suffer from erosion and sedimentation. The land resource is damaged when topsoil and nutrients are removed through sheet erosion. The basic productivity of the land is drastically reduced as a result. Erosion becomes an even more significant problem when it occurs as rill and gully erosion. In this form not only topsoil but underlying material is removed. Erosion in this form reduces crop yields, or more seriously, removes these areas from production. It also enhances the conditions for the introduction of less desirable vegetative species,

lowers water tables, and causes roads and trails to be relocated.

Sediment also becomes a problem when it is deposited in irrigation ditches and fields. The life and storage capacity of ponds are reduced by filling with sediment. Sediment deposition in streams can also cause stream channel widening and other deterioration which may contribute to potential flooding. Additional problems are created when sprinkler heads clog and pumps and sprinkler units wear from the abrasive action of muddy water. Other irrigation structures are also adversely affected or damaged by washing out or filling with sediment.

Erosion and sedimentation increases operation and maintenance costs when it becomes necessary to clean ditches and canals, repair pumps and sprinkler systems, remove deposits from fields, smooth gullies, and otherwise alter agricultural operations.

Municipal and Industrial Water

Sediment has a detrimental effect on public water supplies and industrial water use. Water for domestic use must be free of turbidity. Sediment in a stream will greatly increase the cost of treatment.

Mechanical water treatment plants downstream from the Clarks Fork, which use Yellowstone River water, are located at Billings, Forsyth, Miles City and Glendive. These cities have water with a high sediment content. Laurel, located immediately upstream from the Clarks Fork, has relatively sediment free Yellowstone River water. Most of this difference in sediment content can be attributed to the Clarks Fork.

Cost records of chemicals needed to effectively treat the water from the Yellowstone River were obtained from the cities of Laurel and Billings. A yearly average cost for chemicals per million gallons needed to remove sediment amounted to approximately $4.00 at Laurel and $13.00 at Billings. The total amount of water treated at Billings during 1971 was 5,660 million gallons. If the water at Billings were of the same quality as that at Laurel, a savings of around $50,000 could be realized in treatment costs at Billings during a year's operation. It can readily be seen that a reduction in sediment will have a favorable economic impact on Billings. Treatment costs at Forsyth, Miles City, and Glendive also would be reduced but to a lesser degree than Billings.

Industries located in this part of Montana, which rely on water from the Yellowstone River, are not affected by sediment as much as city water treatment plants.

SOURCES AND CAUSES OF EROSION AND SEDIMENT POLLUTION

In relating to sources of erosion in the basin the following surface categories are used. 1) Forest and alpine; 2) Cropland; 3) Rangeland; 4) Streams, including perennial (flowing all year), intermittent, (flowing part of the year), and ephemeral (flowing only a short time after storms); and 5) Other, such as roads, mining, etc.

Causes, as seen by the study group, are discussed as they relate to each source.

It is obvious that the Clarks Fork basin is highly susceptible to erosion. It has a predominance of erosive soils, steep topography, sparse vegetation, and low rainfall which usually comes as high intensity storms.

A discussion of other causes of erosion and sedimentation that play a definite role in compounding these conditions will follow in this section.

Forest and Alpine Area

These areas produce the highest percentage of water and the lowest amount of sediment. Records of the Forest Service indicate very low turbidity readings from the mountain streams originating in this area.

Although the soil erosion hazard related to sediment production is considered slight, the soil and vegetation of the area is extremely fragile and with mismanagement considerable sedimentation could occur. Soils of the area are generally shallow underlain by bedrock. Stock grazing, timber harvest and mining activity have been virtually curtailed, but

heavy recreational use of parts of the area is causing some sediment production. Some roads and trails have been closed to vehicle travel.

Cropland

Cropland, although comprising less than 1/5 of the Clarks Fork watershed, is one of the major sources of sediment.

Sediment contribution on level to gently rolling dry croplands is minor but similar lands having hilly to moderately steep slopes yield some sediment, especially when unprotected.

Farming across minor drainages creates an unprotected channel for runoff water to pick up sediment. Fallow and newly seeded fields are producing sediment by rill and wind erosion, when soil protection measures such as stripcropping, stubble mulching and windbreaks have not been provided. Susceptibility of croplands to water erosion increases rapidly on the steeper areas.

In the Clarks Fork Basin, fields of dry cropland are small, odd shaped, and interspersed with rangeland. Most fields are producing little sediment, but cropped waterways and steeper slopes are producing larger amounts of sediment.

The practice of placing every acre under production has resulted in land being utilized to the water's edge. Very little vegetation remains to protect stream banks from eroding. Streambank erosion is noticeably greater in these areas.

On cropland, irrigation is the primary sediment producer. Pasture, hayland, and row crops are the major categories of crops irrigated. Row

crops generally produce more sediment because its surface has less cover and is more erosive. Poorly leveled fields and a lack of laterals to control water results in sediment and nutrients being carried off the fields. Nearly all surface irrigation systems produce some runoff water. This runoff adds materially to the extended durations of sediment in the river.

Many canals carry a peak load of water through the irrigating season. The excess water is spilled at the end of the ditch or at tributaries. These activities are used as a substitute for headgate control. Together they cause much gully erosion at the end of the system, in tributaries and to the Clarks Fork.

There are about 300 ditch systems in the Clarks Fork Basin, of which approximately 100 serve more than one farm. These relatively small ditches parallel each other in many places. Land ownership patterns force the ditches to cross and recross. As a consequence extra maintenance and soil disturbance results. Many of their diversions are gravel dikes built in the Clarks Fork channel. The dikes are rebuilt or repaired after each high water period. This activity prolongs the duration of sediment movement in the river.

There is a lack of slope stabilizing structures in ditches. As a result the ditch bottoms erode to restore their natural gradient. Some even meander and trigger massive slumping of hillsides. A lack of waste water ditches and ditches too close to streams have added to sloughing, piping and gully erosion problems in some locations.

Small ditch companies do not find it economically feasible to hire ditch riders and maintenance help. Needed repairs and improvements are

postponed until a water shortage is imminent, in the meantime much erosion and sedimentation occurs.

Rangeland

At present, rangelands in the basin are not only a significant source of sediment, they also produce excessive runoff. This excessive runoff materially augments downstream erosion processes.

Even though some rangeland can be expected to undergo considerable erosion because of its soil types, topography, vegetation and climate, the amount of erosion presently occurring is severe and unwarranted. The cause of this increased erosion on rangeland is basically due to a reduction of desirable vegetation.

Man's activities have affected vegetation condition in the basin considerably. Unfortunately it has not all been desirable, as range condition is generally only fair to poor. It is encouraging to note, however, that soil movement and runoff is being minimized in areas under proper grazing programs, even where topography, soils, and climate are most severe. In these areas headcutting (the head of a deep narrow gully) has slowed and old raw banks are beginning to stabilize.

Storms of high intensity strongly test the drainage basins ability to resist erosion. During the summer of 1972 some locations in sub-basin 14c-6 (N.F. Cherry Creek- Silver Tip Creek) experienced a 50 year frequency storm. Those locations were studied closely. Observations showed that both valley bottoms and upland areas, with poor condition vegetation, underwent considerably more sheet and gully erosion than areas with good condi-

A DETERIORATING RANGE
RESULTS IN GULLY AND
STREAMBANK EROSION

tion vegetation.

Where vegetation is in poor condition, soil is more vulnerable to the erosive action of flowing water and is less able to absorb rainfall. Reduced intake and storage of water by the soil means less moisture for plant growth. Reduced plant growth then compounds the affects already mentioned, by creating artificial droughts. The excessive runoff creates an instability in streams below, resulting in extensive gullying and streambank erosion.

Research conducted by the Agriculture Research Service and the Soil Conservation Service, using a portable rain machine, indicates there is approximately twice as much runoff from poor condition range than from good condition range. On a 40 acre site in poor condition, on silt loam soils, there are 1.5 inches, 1,628,580 gallons, of runoff during a one hour storm of 2.6 inches. It's interesting to note, however, that no runoff occurs on good condition sites with comparable size and soils, experiencing the same intensity. With approximately 60% of the rangeland in the basin in less than good condition, it is not surprising that sheet, rill, gully, and streambank erosion in the basin is severe.

Streams

Even though streams and their flood plains occupy only a very small percentage of the total area of the basin, they are a significant contributor to the present Clarks Fork sediment problem.

Many of the streams in the basin are experiencing various forms of active erosion. The result is a movement of previously deposited

sediment from other sources and the Clarks Fork River. The causes of present increased erosion activity, are not easily determined and vary from stream to stream. While surveying each sub-basin it was evident that some streams are experiencing a more rapid rate of erosion than others, and that the rate of erosion is not constant throughout any given stream. Some of this can be attributed to the fact that most of the streams are still geologically young. Geologic age, however, is not the only reason as the majority of the streams undergoing extensive channel erosion are being influenced by other completely unrelated phenomena which will be discussed below. However, at this time it must be emphasized, even with the risk of being repetitious that there is no one factor causing the problem, it is from a combination of interrelated factors working together.

One major cause is the additional flows due to poor vegetative condition in upland areas.

Another major cause is a lack of soil protection due to denuded or reduced vegetative cover in valley bottoms and on stream banks from overgrazing, trampling and farming too close to streams.

Continual wetting of stream bottoms from flowing wells, springs, reservoirs, interbasin water transfers, and waste water discharges are also very significant. It is a particular problem in ephemeral streams, whose bottoms are composed of unconsolidated, fine grained materials. These delicate soils are also much more erosive in a wetted condition than when dry. The small continual flows saturate the stream bottoms, leaving them in a state of low resistance to the higher velocity flows. Also, unlike wetted soils, dry soils tend to decrease short duration

flows by absorbing the water. Such factors make it difficult to interpret turbidity data from ephemeral streams. Stream flows and turbidity records can not be correlated directly with factors such as high intensity storms and erosive soils because continual wetting is playing a large role.

Many tributaries of the Clarks Fork have deposits of sediment at their mouths. These deposits accumulate during the high water period of the Clarks Fork and are washed out into the river when high water drops, prolonging the high sediment duration.

Sediment is also deposited at various locations in the river when high flows begin to drop. These deposits are carried downstream by the relatively clearer water because of the waters increased ability to carry sediment. This also prolongs the duration of sediment movement in the river.

There are numerous ponds and small reservoirs in the basin, which due to location and design, are adding to the sediment problem rather than reducing it. Although dams slow up sediment movement for a short time they eventually fill up and erode out. Subsequently, both the sediment deposits and the materials used to construct the dam are carried into the stream below which only lengthens the time necessary for the drainage to stabilize.

Stream straightening and other channel manipulations are also adding materially to the erosion problem. Such activities, intended to correct the immediate problem, invariably influence stream hydraulics resulting in an aggravation of other erosion problems elsewhere on the stream. Shortening of stream sections produces higher stream velocities through

the shortened section causing both stream bed and bank erosion in the altered section and in adjacent upstream and downstream sections. Bed material from these areas move into the unaltered stream where normal velocity exists and the material is deposited. This in turn causes a rechanneling and eventual widening effect which causes further bank erosion.

Other Sources of Sediment

Activities pertaining to oil production are having direct and indirect affects on soil erosion locally. Oil spills from broken pipelines and well discharges have affected stream bottoms by killing vegetation. Frequently, land disturbances from the network of roads, pipelines, oil sumps, and well activities, have left the immediate area and the downstream areas vulnerable to erosion and subsequent sediment contribution to the Clarks Fork.

Roads and trails are a prime source of sediment, as their locations were and are generally based on convenience, with little concern for erosion. Rights-of-way usually have limited capability for drainage. In many cases runoff is even concentrated from several natural water courses into one before it is permitted to escape. Excessive slope, improper location of culverts, and unreseeded barrow areas are also contributing factors. //

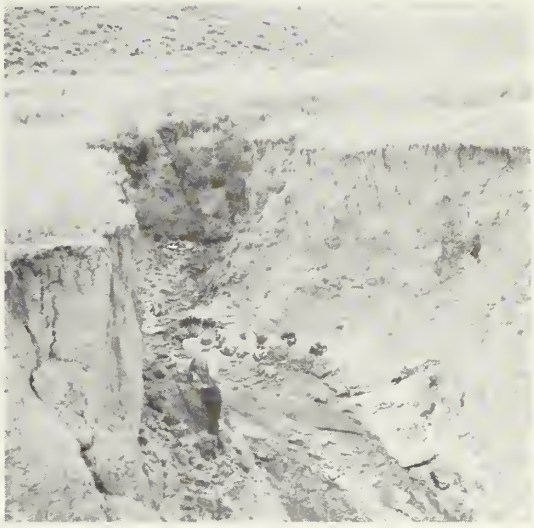
Urban development and feedlots increase sedimentation during storms and runoff periods due to poor location and soil disturbances.

Mining has contributed to the sedimentation problem in past years,

CONTRIBUTIONS TO SEDIMENT POLLUTION

POOR CROPPING PRACTICES

TRAMPLED STREAM BANKS



RESERVOIR SPILLWAYS

ROADWAYS

STREAM CHANNELS

however little activity is presently occurring in the Montana portion of the basin at this time.

Additional Pollution Types

This report is basically limited to sediment problems. There are other types of water pollution occurring in the drainage that are worthy of mention. Further investigation and sampling of this drainage area would no doubt show pesticide, nitrate, and phosphate pollution.

Chemical pollution from oil has been found at the mouth of the Clarks Fork and at times near Billings. Scheduled for completion late in the fall of 1972 is a waste water re-injection system in the Elk Basin Oil Field, whereby the waste water will be re-injected back into the ground and not discharged into the drainage.

Sewage treatment lagoons are located at Belfry, Bridger, Fromberg, and Edgar. The lagoons at Belfry and Edgar do not overflow while the units at Bridger and Fromberg overflow at a continuous, but very low rate. Effects of these discharges have not been quantified but are thought to be minor.

Nutrients and chemicals used in farmyards, fields and feedlots are also likely pollutants in the drainage. There is no data available on water pollution from these sources.

CLARKS FORK - ZIMMER CREEK (Sub-basin 14c-3)

This sub-basin, lying in the high mountain area of the Beartooth Range, is approximately 6 miles long and 18 miles wide. Annual precipitation varies from 35 to over 70 inches. Elevations vary from 9,000 feet to 11,000 feet. The area is abundant with numerous natural lakes. Native vegetation includes conifers and tall grasses in the lower elevations, and tundra species in the higher elevations.

Soils

Mountainous and Alpine Association:

Shallow, non-limey, gravelly and stony soils of high plateaus and precipitous barren rock canyons.

This association has slight erosion hazards.

LAND USE		LAND OWNERSHIP	
Trees	29,000	Private	2,420
Grass	1,328		
Urban	72	National Forest	71,445
Alpine	37,593		
Water	5,872	TOTAL ACRES	73,865
TOTAL ACRES	73,865		

Observations

This sub-basin is relatively undisturbed and largely under intensive management plans of the U. S. Forest Service.

Measurements taken during Forest Service studies indicate low sediment yields occur from this area. The committee decided that a sampling station was not necessary at the mouth of this sub-basin.

LINE CREEK (Sub-basin 14c-5)

Only about 10 percent of this sub-basin lies in Montana. This portion is in a 40 inch annual precipitation belt. Elevations range from 7,000 to 9,000 feet. Vegetation includes bunchgrasses, aspen and conifer species.

Soils

Mountainous and Alpine Association:

This association is described in 14c-3.

LAND USE		LAND OWNERSHIP	
Trees	5,900	Private	240
Grass	3,459		
Alpine	299	National Forest	11,577
Water	7		
Brush	2,292	B.L.M.	140
TOTAL ACRES	11,957	TOTAL ACRES	11,957

Observations

Road and trail locations contribute to the only known soil loss of this area. However, no measurements of turbidity were made on this sub-basin. The committee previously determined that the sediment yield from this portion of the basin would be relatively insignificant to the entire study.

PAT O'HARA CREEK (Sub-basin 14c-4), BIG SAND COULEE (Sub-basin 14c-4a), N.F. CHERRY-SILVER TIP (Sub-basin 14c-6)

The three basins will be discussed as one unit.

The area is located on the east side of the Clarks Fork in the southeastern portion of the study area. It is 30 miles long and 19

miles wide at the state line and gradually tapers to a point near Fromberg.

Elevations vary from 3,527 feet at Fromberg to 4,600 feet in the upland areas near the headwaters. The terrain is predominantly steep and broken throughout the upper areas, with gently sloping irrigated valleys near the Clarks Fork River. Sand Coulee, Hollenbeck, Silver Tip, Cottonwood, Jack, Bridger, Rush Water and Skunk Creeks are the major tributaries in the area. Few run water year-round and most receive, or have received additional flows by interbasin transfer systems from the Clarks Fork, Shoshone River and wells.

Annual precipitation varies from less than 6 to as much as 12 inches, most of which falls during the growing season in high intensity, short duration storms.

The sub-basin is predominantly rangeland. Sagebrush is the major vegetation type with numerous parallel strips of intermingled barren areas. Saltbush and greasewood are also evident in much of the lowlands. Ground cover is considered sparse, especially in the southern portions.

Soils

Heldt Association: (20% of sub-basin)

Deep, well-drained, alluvial soils on stream terraces and fans.

This association is dominated by silty clay loam, clay loam and silt loam soils. Generally irrigated, the soils of this association are used for row crops, small grains, hay and pasture. Originally deposited by water action, the soils have a strong tendency to erode easily when subjected to even small amounts of flowing water. This association is shown as severe on the soil erosion hazard map.

Midway-Travessilla Association: (80% of sub-basin)

The association is generally shallow, light-colored clay and sandstone soils of the shale and sandstone upland bedrock plains. These occur in hilly to steep and excessively drained areas. It is characterized by narrow divides with steep side slopes. The east facing exposures are generally barren shale and sandstone cliffs. The west slopes are moderately steep with alluvial soils in the drainageways. The association is occupied by a dendritic (tree-like) drainage pattern with stream channels cutting deep into bedrock. Predominantly used for grazing, this highly erosive soil is dependent strongly upon grass and other vegetative cover for protection against the high intensity rainstorms.

Pat O'Hara Creek (Sub-basin 14c-4)

LAND USE		LAND OWNERSHIP	
Dry Crop	215	Private	797
Irr. Crop	112		
Grass	449		
Urban	9		
Water	12		
TOTAL ACRES	797	TOTAL ACRES	797

Big Sand Coulee (Sub-basin 14c-4a)

LAND USE		LAND OWNERSHIP	
Dry Crop	741	Private	4,118
Irr. Crop	968		
Grass	917	State	840
Urban	122		
Water	142	B.L.M.	8,394
Brush	10,462		
TOTAL ACRES	13,352	TOTAL ACRES	13,352

N.F. Cherry - Silver Tip (Sub-basin 14c-6)

LAND USE		LAND OWNERSHIP	
Dry Crop	2,232	Private	67,081
Irr. Crop	10,633		
Trees	5,850	State	7,651
Grass	21,596		
Urban	1,487	B.L.M.	79,210
Water	150		
Brush	111,994	TOTAL ACRES	153,942
TOTAL ACRES	153,942		

Observations

The grassland, managed largely by the Bureau of Land Management, is increasingly undergoing improved management practices. In cooperation with the B.L.M., the Bureau of Reclamation is assisting in a rehabilitation program of the Big Sand Coulee Basin. It involves a variety of erosion control measures such as grass seeding, livestock management and contour furrowing.

Oil production practices in the upper Silver Tip drainage are having considerable adverse effect in sediment and chemical pollution in Silver Tip Creek and the Clarks Fork River. Oil spills are common occurrences and, according to the Environmental Protection Agency, Silver Tip Creek is not recommended for livestock consumption. Spilled oil kills vegetation in the stream bottoms, leaving the soil unprotected from runoff. Numerous oil sumps, which have been built in the main channel and side tributaries of Silver Tip, are only sporadically successful in holding the spills. In the meantime, the sumps either wash out or fill completely with sediment at an amazingly fast rate, which only adds to the sediment problem in the basin. It is estimated that a daily average of 1,759,000 gallons of waste water from oil production are discharged into Silver Tip

Creek, which was historically an ephemeral stream. Roads constructed for oil production have increased runoff and channeled flows. Roadsides, pipeline disturbances and buried oil spills are being left unseeded. Several miles of oil spills buried in 1972 disturbed or removed all vegetation on the sides and bottoms of some tributaries. Therefore, 1973 runoff is highly likely to trigger a new cycle of valley trenching and widening in those tributaries and the streams below. The result will be sediment production for many years to come.

Range condition is less than desirable throughout most of the area, but those areas which benefit from intensive grazing management have shown a remarkable improvement in condition. Thus far, 37,477 acres are under intensive management by the B.L.M. and by 1974 there should be a total of 86,405 acres so managed.

Numerous ponds and reservoirs are completely filled with sediment. It is evident that the reservoir life in this area has been extremely short.

Improper construction of roads and trails has also increased the sediment problem. Many of such roads wash out yearly and gullying has been caused by improper placement of culverts. Many lightly used roads traverse drainages by filling rather than by contouring the natural bottoms. The new B.L.M. road in Cottonwood Creek is an exception, as adequate drainage and erosion reduction was planned for in its location. Proper design and reseeded sides have reduced erosion remarkably.

Continual wetting of historically ephemeral streams with water from the Clarks Fork River, Shoshone River and uncapped wells has increased erosion. Wetting saturates the soils, leaving them in a state of low

resistance to the highly erosive action of torrential flows. No less than 26 miles of ephemeral streams have been used to carry these additional flows.

Many tributaries are suffering from active valley trenching or widening. This is especially evident in Silver Tip Creek, Sand Coulee and Cherry Creek. Even though there is evidence of some improvement, many are causing increased damage to roads, farms, and bridges.

Irrigation practices are causing some problems. Using too much water and receiving water from inter-basin transfers are the major adverse influencing factors.

Eight samples for turbidity measurements were taken at site 4 on Big Sand Coulee with values ranging from a high of 1470 JTU's in March 1972, to a low of 15 JTU's in July 1972, with a mean value of 244 JTU's. Seven samples were taken at site 10 on Silver Tip Creek. Turbidity values ranged from a high of 6850 JTU's in March 1972 to a low of 15 JTU's in May 1972, with a mean value of 1023. Thirteen samples were taken at site 9 on Cottonwood Creek. Turbidity values ranged from a high of 2100 JTU's in March 1972, to a low of 5 JTU's on July 26, 1972, with a mean value of 192.6 JTU's. These three sampling sites, located near the mouths of the drainages, indicate considerable sediment entering the Clarks Fork from these tributaries.

CLARKS FORK - RUBY CREEK (Sub-basin 14c-7)

This sub-basin is approximately 27 miles long and 12 miles wide. It is located to the west of the Clarks Fork River from the state line on the south, to Fromberg on the north and to Red Lodge on the west.

Elevations vary from 3,527 feet at Fromberg to over 9,000 feet in the small mountainous region in the south. Within the hilly to undulating and slightly broken terrain are the following major tributaries: Ruby Creek, Grove Creek, Bear Creek, Dry Creek, and Sand Creek. These creeks are generally intermittent depending upon flows from interbasin water transfer systems from Rock Creek. The streams originating in the mountains are usually perennial until they reach the alluvial fans at the base of the mountains, where they become intermittent.

Precipitation is generally low in the basin, ranging from less than 6 inches per year in the far southeast portion of the basin to nearly 30 inches per year in the mountainous portion. The basin lies generally in a 10-14 inch precipitation belt. The drier areas experience very high intensity short duration storms, while the wetter areas usually receive precipitation more gradually and with considerably more snow.

Vegetation is dominantly sagebrush intermingled with bunchgrasses in the lower elevations and bench lands, but a narrow band of tall grasses and conifers is associated with the mountainous portion. Greasewood and saltbushes are common in valley bottoms, with occasional cottonwoods and willows near streams. Ground cover varies throughout the basin, but it is very sparse in those areas having low rainfall and highly erosive soils.

Soils

Heldt Association: (25% of sub-basin)

This association is described in sub-basin 14c-6.

Midway-Travessilla Association: (55% of sub-basin)

This association is described in sub-basin 14c-6.

Romberg Association: (20% of sub-basin)

Gravelly and stony loam soils on glacial outwash terraces and fans in arid regions.

The area includes Mill Draw, Ruby Creek and Grove Creek. It is characterized by broad sloping flats and benches cut with well defined stream channels that have eroded to bedrock.

These soils are formed on old, deep glacial and limey water deposited materials and erode rapidly when unprotected and subjected to the cutting action of occasional storm waters.

This association has a severe erosion hazard rating.

LAND USE		LAND OWNERSHIP	
Dry Crop	4,124	Private	127,924
Irr. Crop	11,385		
Trees	7,660	State	7,288
Grass	96,991		
Urban	1,511	National Forest	5,124
Brush	47,229		
Water	320	B.L.M.	28,884
TOTAL ACRES	169,220	TOTAL ACRES	169,220

Observations

Tributaries flowing into the Clarks Fork show large deposits at their mouths. Sediment deposits accumulate during high water periods of the Clarks Fork and are washed out into the river when the water level drops, prolonging the high sediment duration. This was particularly evident at the mouth of Dry Creek.

Erosion processes in stream channels are active throughout most of the basin. Most streams have obtained relatively stable bottoms, but bank erosion is increasing especially in streams receiving additional flow from interbasin transfer systems. It is estimated that 25 percent

of all stream mileage is suffering from streambank erosion.

In the upper reaches of Bear Creek and Dry Creek, there are large gullies measuring up to 50 feet deep and 50 feet wide. These gullies result from large quantities of irrigation water dropping hundreds of feet in short distances. Most of these gullies are tending to stabilize and are now contributing significantly less sediment than in past years. Continual wetting of ephemeral stream bottoms from interbasin transfer water is a major influencing factor on stream erosion processes in these two tributaries. There are 38 miles of streams and tributaries being used as carriers by interbasin transfer systems.

Some active erosion is taking place in side tributaries in the form of gullies and headcuts, but many of them are beginning to heal naturally in areas with better range condition.

Most valley bottoms have been very heavily grazed, and a significant portion of the upper reaches of the watershed suffers from the same activity. More erosion activities were observed in areas of poor range condition, especially in valley bottoms.

Using too much irrigation water, improper location and a lack of waste water ditches, poor location and excessive slope of ditches, and farming too close to streams are also factors playing a significant role in active erosion processes.

Poor location and design of roads, culverts, and trails are causing extensive problems in some areas. Some roads have actually been moved two or three times, as ruts ultimately become gullies up to 5 feet deep.

Turbidity values for samples taken at three sites in this sub-basin were very high. Twelve samples were taken at site 12 - Dry Creek, with

a high value of 3950 JTU's in October 1971, a low of 20 JTU's in July 1972, and a mean value of 554 JTU's. Eight samples were taken at site 11 - Sand Creek with a high turbidity of 4650 JTU's in March 1972, a low of 8 JTU's in April 1972, and a mean value of 620 JTU's. Eleven samples were taken at site 3 on Bear Creek showing a high value of 1210 JTU's in March 1972, a low of 10 JTU's in October 1971, with a mean value of 188 JTU's. These high values indicate considerable sediment entering from these drainages.

UPPER ROCK CREEK (Sub-basin 14c-8)

The sub-basin is located in the headwaters of Rock Creek in the Beartooth Range. The area is about 16 miles long and 18 miles wide, with elevations ranging from 6,000 to 10,000 feet. Annual precipitation varies from 25 to 60 inches. Native vegetation includes conifer stands and tall grasses in the lower elevations and tundra species in the alpine areas.

LAND USE		LAND OWNERSHIP	
Dry Crop	652	Private	7,192
Irr. Crop	40		
Trees	32,413	State	752
Grass	69,315		
Urban	684	National Forest	112,825
Alpine	16,948		
Water	877	B.L.M.	160
TOTAL ACRES	120,929	TOTAL ACRES	120,929

Soils

Mountainous and Alpine Association:

This association is described in 14c-3.

Observations

Heavy grazing occurred on the high plateau area from the late 1800's to 1960. Since then, grazing permits were rescinded and vegetal characteristics have improved.

Chrome mining in the 1940's was a cause of sedimentation. However, the present conditions indicate the affected areas are now insignificant sources of sediment.

Virtually no timber harvests have taken place.

The committee determined that no sampling station was necessary at the mouth of this sub-basin because of the slight erosion hazard classification, and data supported by the Forest Service.

RED LODGE - ROCK CREEK (Sub-basin 14c-9)

The basin is approximately 30 miles long and 15 miles wide, with Cooney Reservoir on the north, Red Lodge on the south, Luther on the west, and Roberts on the east.

Elevations vary from 4,100 feet at Boyd to over 9,000 feet in the mountainous portion. Starting in the mountains, the terrain drops rapidly to gently rolling bench lands and swails in the central portion to hilly in the north. The major streams are Volney Creek, Willow Creek, Clear Creek, Cottonwood Creek, Red Lodge Creek and the middle reach of Rock Creek. The majority are perennial streams receiving additional flows from interbasin transfer systems.

Precipitation ranges from 30 inches per year in the southern portions to 14 inches in the northeast corner. Sixteen to eighteen inches could

be considered a fair average for the basin. Precipitation usually falls as rain in the lower elevations during the growing season with increasing amounts of snow toward the higher elevations, with very heavy snowpack in the mountainous region.

The sub-basin is predominantly rangeland with sagebrush and bunchgrasses in the north, mid to tall grasses with aspen filled swails in the central portion to tall grasses and conifers in the mountainous portion. Ground cover is very good, with only a few exceptions in the northern portion.

Soils

Heath-Charlos Association: (45% of sub-basin)

Deep and moderately deep loamy and clay loam soils on glaciated terraces and valley side slopes.

It is characterized by moderate to steep bedrock uplands and by benches of glacial outwash materials cut with deep narrow valleys.

Largely rangeland and in the 16 to 24 inch rainfall area, this association generally has a slight erosion hazard rating. Narrow stream bottoms have a severe rating and erode readily when natural brush and tree cover is removed.

Maurice-Woodrock Association: (30% of sub-basin)

Moderately deep, well drained soils of stream terraces, alluvial fans and footslopes.

This association forms the valley of the main drainageways and the footslopes and sloping fans of the mountains. Stream channels are well defined and in places have cut deep into the gravel beds.

Stream bottoms have a moderate to severe erosion hazard rating. The benches and divides generally carry a slight rating.

Absarokee-Sinnigam Association: (25% of sub-basin)

Deep to shallow soils with clayey subsoils over shale and sandstone on broad ridge tops and steep sloping uplands.

Steep branching drainageways forming many gently to strongly sloping ridge tops characterize this association. It includes the valley side slopes and divides in the Cooney Reservoir area.

Generally the erosion hazard rating is severe in the bottoms of the drainageways, giving way to moderate and slight on the valley side slopes and ridges.

LAND USE		LAND OWNERSHIP	
Dry Crop	27,464	Private	178,269
Irr. Crop	39,308	National Forest	18,276
Trees	16,570	State	10,292
Grass	119,076	B.L.M.	693
Urban	3,897	F & G	250
Water	1,465	TOTAL ACRES	207,780
TOTAL ACRES	207,780		

Observations

This sub-basin is experiencing erosion problems in the Red Lodge Creek drainage. At present it is relatively insignificant to the Clarks Fork sediment problem. A large percentage of the sediment derived from this basin is deposited in Cooney Reservoir. According to a survey conducted by the Fish and Game Department in 1970 (unpublished), the reservoir capacity has been reduced by over 5,400 acre feet since its construction in 1936. This is approximately 1/5 of its original capacity.

Streambank erosion is quite active throughout the basin and is causing some damage to roads and farm building sites. Scattered riprap

projects have been installed to help correct this. Farming too close to streams and removal of brush and vegetation near banks have increased streambank erosion in several areas of this sub-basin. Some channel straightening is also augmenting the problem.

Soil slumping is causing considerable damage to roads and irrigation systems. Roads have to be repaired annually in numerous locations. Many ditches have been damaged beyond reasonable repair costs.

Grazing is fairly heavy throughout the basin, but due to the dense ground cover of sod-forming vegetative species the soil is relatively well protected and shows only occasional scars of active erosion in the upland areas.

Excessive irrigation water, steep and poorly located ditches and uncontrolled spilling of waste water into natural tributaries have caused many gullies and other forms of erosion.

There are 78 miles of streams and tributaries being used as carriers for interbasin transfer flows.

There were no samples taken in the sub-basin for turbidity measurement. However, Willow Creek and Volney Creek were noted to be turbid during the survey of this sub-basin.

ELBOW - LOWER ROCK CREEK (Sub-basin 14c-10)

This diamond-shaped sub-basin, located in the lower portion of the study area, is about 36 miles long and 12 miles wide. Elevations range from 3,300 feet to 5,200 feet. Annual precipitation ranges from 13-17 inches. Vegetation of the area includes bunchgrass type species

with scatterings of sagebrush, juniper, pine and conifers. Willows, cottonwood and other decidious species occupy flood plain areas of Rock Creek and Elbow Creek.

Soils

Heldt Association: (45% of sub-basin)

This association is described in sub-basin 14c-6. Located close to Rock Creek, Elbow Creek and the Clarks Fork River, this association carries a severe erosion hazard rating. In the higher elevations the rating changes to moderate and slight.

Absarokee-Sinnigam Association: (35% of sub-basin)

This association occupies the middle reaches of the Elbow Creek drainage. It is described in sub-basin 14c-9.

Wayden-Cabba Association: (20% of sub-basin)

Shallow and moderately deep clay soils of the shale and sandstone uplands.

This association occupies the upper reaches and the divides on both sides of Elbow Creek. It is characterized by broad to narrow, strongly sloping to steep divides and well-defined branching drainageways. Generally the area has shallow, clayey or loamy soils over shale or sandstone. The stream channels have cut into the bedrock in most places.

This area varies equally between slight, moderate and severe erosion hazard ratings. The severe rating generally being in the drainage bottoms.

LAND USE		LAND OWNERSHIP	
Dry Crop	20,865	Private	88,402
Irr. Crop	19,100		
Trees	3,770	State	2,541
Grass	44,318		
Urban	2,849	B.L.M.	359
Water	400		
TOTAL ACRES	91,302	TOTAL ACRES	91,302

Observations

Approximately 60 percent of Elbow Creek has active erosion in its channel. The main problem exists in the lower two-thirds of the watershed. Large sections of soil slough into the stream, prolonging the duration of high sediment content in the stream. Sheer banks measuring to a depth up to 20 feet were evident throughout this area. Some of the stream is tending to stabilize, as vegetation is becoming established in areas where grazing has been reduced. Poor vegetal cover in some upstream areas is definitely extending the time necessary for the stream to stabilize. Additional water is being supplied to some of the streams by interbasin transfers.

Channel changing and the use of many inadequate irrigation diversion structures are affecting stream stabilization. This is especially obvious in the Rock Creek portion of this sub-basin. Fallen cottonwood trees and snags are also affecting stream flows.

Turbidity samples on Rock Creek at site 1 indicate moderate sediment loads. Fourteen samples were taken, with a high of 55 JTU's in March 1972, a low of 0 JTU's in January 1972, and a mean value of 11.23 JTU's. Only five samples were taken at site 13 on Elbow Creek. A high turbidity of 3625 JTU's was recorded in March 1972 and a low of 8 JTU's in April

1972 with a mean value of 622.3 JTU's. Elbow Creek appears to be a significant source of sediment entering the Clarks Fork.

LOWER CLARKS FORK, EAST SIDE (Sub-basin 14c-11)

This sub-basin is located in the far northeast corner of the basin and covers an area approximately 16 miles long and 10 miles wide. Elevations vary from 3,300 feet to 4,800 feet. The 12-15 inch annual precipitation zone covers the entire area. Vegetation is dominately grass. Bunchgrass type species prevail except for occassional heavy stands of big sagebrush. Cottonwoods are numerous in the lower reaches of the tributaries.

Soils

Haverson-Glenberg Association: (5% of sub-basin)

Deep, loamy, well drained soils of the flood plains and narrow stream valleys.

This association is dominated by loam, silty clay loam and sandy loam soils with some saline-alkaline areas. They occupy the nearly level broad stream terraces and alluvial fans adjacent to the Clarks Fork. These soils are subject to flooding during periods of high water. They are used primarily for irrigated crops.

The river channel is well defined and in places is cutting into the deep alluvium and gravel beds. River banks and side drainage areas slough readily when moist.

This association has a severe erosion hazard rating.

Nunn-Wormser Association: (15% of sub-basin)

Deep and moderately deep soils on intermediate stream terraces and alluvial fans.

Soils of this association are mostly well drained, light colored loam and clay loam soils with clay subsoils and shallow loam soils on sandstone. They occupy level to moderately sloping landscapes in the Bluewater Creek area southeast of Fromberg. A large percentage of the area is used for irrigated and dryland crops.

The lower areas adjacent to the Clarks Fork River flood plain have slight and moderate erosion hazard ratings. The areas in the upper reaches of Bluewater Creek rate severe.

Marias-Kyle Association: (25% of sub-basin)

Nearly level to strongly sloping, deep well drained soils on shale uplands.

This combination of soils occupies the midreaches of Cottonwood, Five Mile and Two Bear Creeks east of Edgar. They are generally clay soils over shale on medium to strongly sloping footslopes and fan terraces.

On gentle slopes, the erosion hazard is slight and increases to severe on the steeper lands.

Absarokee-Sinnigam Association: (35% of sub-basin)

This association is explained in sub-basin 14c-9. The topography that characterizes this association can be found in the upper reaches of Cottonwood, Five Mile and Two Bear Creeks on the eastern edge of the sub-basin.

About 60 percent of the area is used for producing small grains and the remainder is rangeland.

Wayden-Cabba Association: (10% of sub-basin)

This association is found in the headwaters of Bluewater and Bridger Creeks and is described in 14c-10.

Lap-Windham Association: (10% of sub-basin)

Steep, shallow and deep loamy soils and limestone outcrop of the mountains.

This association is located on the southeastern boundary of the sub-basin. Deep loamy soils occupy the north and east facing slopes. The shallow soils occupy the south and west facing limestone bedrock slopes. The drainageways are steep limestone canyons.

This area has a slight to moderate erosion hazard rating.

LAND USE		LAND OWNERSHIP	
Dry Crop	19,199	Private	111,346
Irr. Crop	7,082	State	6,296
Trees	3,842	F & G	90
Grass	102,064	B.L.M.	9,104
Urban	711	Indian	6,348
Water	286	TOTAL ACRES	133,184
TOTAL ACRES	133,184		

Observations

This sub-basin is very divided in relation to its present erosion situation. The northern portion is very stable while the southern portion is experiencing many more forms of active erosion. Cottonwood Creek is the approximate boundary.

Vegetation is less than desirable on about 65% of the area, especially the valley bottoms. Some improvement programs have been implemented.

Dry land farming practices in the northern portion have probably had an effect on grazing practices, as range and cropland are intermingled.

Extensive erosion and sedimentation is occurring in reservoirs and spillways in upper Five Mile Creek and Bluewater Creek. Several dams are completely filled with sediment with each having large gullies in their spillways.

One flowing well was draining into Cottonwood Creek.

Approximately 29 miles of the Clarks Fork borders this sub-basin. It is estimated that 30% of its banks are influenced by active stream-bank erosion. About 2% of the area has been treated to prevent land loss.

Few ephemeral streams in this sub-basin are being influenced by additional flow from irrigation waste water. It is the least influenced of all sub-basins containing irrigation.

In relation to all tributaries within the sub-basin, Cottonwood Creek is effected the most by channel erosion activities.

Soil piping erosion (underground tunnels) is active on the lower portion of Five Mile Creek.

Although somewhat minor, locations of roads, trails, and culverts are also contributing to the sediment problem.

Occasional sediment deposits were noted at the downhill sides of some fields having steep slopes.

Samples were taken on two tributaries in this sub-basin; site 2, Bluewater Creek, and site 5, Five Mile Creek. Fifteen samples were taken on Bluewater Creek, with a high value of 80 JTU's recorded in August 1972, a low of 6 JTU's in February 1972, with a mean value of 39.4 JTU's. These turbidity readings indicate moderate sediment loads which appear to be fairly constant throughout the year. Nine samples were

taken on Five Mile Creek with a high of 150 JTU's in August 1972, a low of 1.5 JTU's in April 1972, and a mean value of 69.5 JTU's. The high readings for these sites occurred during a rainy period in mid-August instead of during spring runoff periods.

TURBIDITY DATA

Description of Sampling Sites

A. Clarks Fork at bridge east of Edgar.

B. Clarks Fork at bridge east of Fromberg.

C. Clarks Fork River at Chance bridge.

D. Clarks Fork River at canyon exit about 10 miles into Wyoming.

1. Rock Creek at highway crossing south of Rockvale.

2. Bluewater at bridge on county road one mile east and one and one-half miles south of Fromberg.

3. Bear Creek at bridge in Belfry.

4. Big Sand Coulee on road to Clarks Fork Ranch about one-half mile into Wyoming.

5. Five Mile Creek at bridge one-half mile east and one-half mile north of Edgar.

6. Skunk Creek at county road crossing about three miles north and one mile east of Bridger.

7. Rushwater Creek at county road one mile east and one mile south of Bridger.

8. Bridger Creek at county bridge crossing just east of Highway 310.

9. Cottonwood Creek at county road crossing four miles south of Bridger.

10. Silver Tip Creek at crossing with Highway 308.

11. Sand Creek at rest area on Highway 310 about three and one-half miles north of Bridger.

12. Dry Creek along highway about three and one-half miles north of Belfry on Highway 308.

13. Elbow Creek at crossing on Highway 310 about one mile south of Edgar.

Discharge & Turbidity Measurements on Tributaries to the Clarks Fork Yellowstone River

LOCATIONS

DATE	cfs & JTU*	1	2	3	4	5	6	7	8	9	10	11	12	13
09/20/71	cfs										4.0			
	JTU										65.0			
10/14/71	cfs									0.5			1.0	
	JTU	6.0	28.0	10.0	25.0					27.0			3950.0	
11/03/71	cfs									0.5			1.0	1.0
	JTU	5.0	25.0	23.0		48.0	9.0		30.0	31.0			265.0	19.0
01/17/72	cfs													
	JTU	0.0	25.0								15.0			
02/08/72	cfs													
	JTU		6.0											
03/07/72	cfs					9.0			16.0	7.0	16.0	14.0	11.0	45.0
	JTU	55.0	67.0	1210.0	1470.0	51.0			460.0	2100.0	6850.0	4650.0	1535.0	3625.0
04/04/72	cfs					2.0			7.0	1.0		1.0	3.0	4.0
	JTU	3.5	15.0	60.0		7.0	2.0		30.0	15.0		24.0	110.0	30.0
04/19/72	cfs					1.5	0.2	1.0	3.75	0.2		0.2	6.0	8.5
	JTU	2.5	25.0			1.5	3.5	800.0	20.0	5.0		8.0	45.0	8.0
05/03/72	cfs								2.0			7.5	3.0	6.0
	JTU	10.0	40.0	55.0		Dry	2.5		30.0	15.0		44.0	30.0	12.0
05/18/72	cfs			4.5		8.0	4.0	4.0	6.0	3.75			4.0	
	JTU	10.0	38.0	150.0	30.0	150.0	105.0	150.0	160.0	50.0	90.0		220.0	
06/05/72	cfs					4.0	3.0	4.0	6.0	3.75		4.5	4.0	
	JTU	24.0	55.0	140.0	190.0	110.0	90.0	60.0	32.0	50.0	60.0	70.0	275.0	
06/19/72	cfs					4.0	3.0	4.0	6.0	3.75			4.0	
	JTU	10.0	40.0	225.0	100.0	60.0	140.0	150.0	275.0	40.0		60.0	60.0	
07/04/72	cfs					4.0	2.0	4.0	6.0	3.75			4.5	
	JTU	4.0	23.0	70.0	55.0	50.0	40.0	40.0	42.0	28.0	55.0		38.0	
07/26/72	cfs						0.75	1.5	4.5	2.0		7.5	4.5	
	JTU	4.0	55.0	65.0	15.0		38.0	20.0	150.0	6.0	15.0	20.0	20.0	
08/17/72	cfs						1.0	1.5	4.5	2.5		7.5	4.5	
	JTU	3.0	80.0	55.0	65.0	150.0	85.0	90.0	30.0	85.0		80.0	110.0	
09/04/72	cfs													
	JTU	9.0	70.0				62.0	55.0	70.0	25.0				
HIGH	JTU	55.0	80.0	1210.0	1470.0	150.0	140.0	800.0	460.0	2100.0	6850.0	4650.0	3950.0	3625.0
LOW	JTU	0.0	6.0	10.0	15.0	Dry	2.0	20.0	20.0	5.0	15.0	8.0	20.0	8.0
MEAN	JTU	11.23	39.4	188.0	244.0	69.5	52.4	170.0	110.0	192.6	1023.0	620.0	554.0	622.3

*Explanation: cfs= Cubic feet per second, Discharge
JTU= Jackson Turbidity Unit, Turbidity measurement

U.S.G.S. discharge records for Rock Creek, Silver Tip Creek and Bluewater Creek not available as of January 1, 1973

Discharge & Turbidity Measurements on the Mainstem Clarks Fork Yellowstone River

DATE	DISCHARGE (cubic feet per second)	TURBIDITY (Jackson Turbidity Units)			
	Silesia, Mt.	STATION A Edgar, Mt.	STATION B Fromberg, Mt.	STATION C Chance, Mt.	STATION D Canyon, Wy.
09-20-71	793				
10-14-71	748	12	16	8	
11-03-71	698	12		16	
01-17-72	550			0	
02-08-72	374				
03-07-72	690	500	640	62	3
04-04-72	427	4		2.7	
04-19-72	485	15	15	4.5	1.5
05-03-72	522	25	25	5	5.0
05-18-72	2490	125	90	30	10.0
06-05-72	8520	70	75	40	30.0
06-19-72	6430	32	25	30	10.0
07-04-72	2840	20	12	15	5.0
07-26-72	1400	13	28	3	2.0
08-17-72	1300	150	93	20	34.0
09-04-72	910	39	70		5.0
HIGH	8520	500	640	62	30
LOW	374	4	12	0	2
MEAN	1823.6	78.3	99.0	18.7	10.55

Discharge from U.S. Geological Survey gauging station at Silesia is Preliminary and subject to change.

APPENDIX

A

A REMOTE SENSING STUDY OF SEDIMENT IN THE CLARKS FORK YELLOWSTONE RIVER

James F. Ruff
and
Morris M. Skinner
Colorado State University
Fort Collins, Colorado 80521

John W. Keys III
Bureau of Reclamation
Billings, Montana 59103

Dennis Waugaman
Colorado State University
Fort Collins, Colorado 80521

November 1972

Prepared for

BUREAU OF RECLAMATION
Department of the Interior
Denver, Colorado 80225

CER72-73JFR-MMS6

A REMOTE SENSING STUDY OF SEDIMENT IN THE CLARKS FORK YELLOWSTONE RIVER

Prepared For:

Bureau of Reclamation
Department of the Interior
Denver, Colorado

By

James F. Ruff

Morris M. Skinner

John W. Keys III

Dennis Waugaman

Civil Engineering Department
Colorado State University
Fort Collins, Colorado

November, 1972

ABSTRACT

Interpretation of remotely sensed data was used to locate and identify perennial and intermittent tributaries to the Clarks Fork Yellowstone River, Rock Creek and Red Lodge Creek located in southcentral Montana and northwestern Wyoming. Color infrared photography and thermal infrared imagery were obtained which covered the river and a strip of the flood plain approximately 1 1/2 to 2 1/2 miles wide. Inflows and contributing sources of sediment from tributaries, ditches, and gullies to the Clarks Fork Yellowstone River were located and identified. Results of the study indicate that aerial color infrared photography and thermal infrared imagery are practical tools for locating and identifying inflow of sediment laden water to a river system.

CONTENTS

	Page
LIST OF FIGURES	iv
LIST OF TABLES	v
INTRODUCTION	1
Purpose of Study	1
Background	1
Scope of Investigation	2
BASIN CONDITIONS	4
General Description	4
Terrain Conditions	4
Antecedent Weather Conditions for Remote Sensing Flights	5
PROCEDURE	7
Reconnaissance	7
Ground-Truth Data Program	8
Airborne Data	8
Data Analysis	20
Photography and Radiation Principles	21
INTERPRETATION	23
CONCLUSIONS	91

LIST OF FIGURES

Figure		Page
1	Location Map of the Clarks Fork Yellowstone River Remote Sensing Project	3
2	Drainage Area Map of the Clarks Fork Yellowstone River Showing Ground-Truth Collection Program for Aerial Remote Sensing Study	9
3	Relationship of Suspended Solids in Parts Per Million (ppm) and Turbidity in Jackson Turbidity Units (JTU)	24
4	Confluence of the Clarks Fork Yellowstone River and the Yellowstone River	25
5	Confluence of Dry Creek and the Clarks Fork Yellowstone River and Environs	27
6	Confluence of Rock Creek and Clarks Fork Yellowstone River	28
7	Confluence of Bennett Creek and Clarks Fork Yellowstone River	28
8	Thermal Infrared Imagery of Confluence of Bennett Creek and Clarks Fork Yellowstone River	29
9	Thermal Infrared Imagery of the vicinity of Fromberg, Montana (showing Blue Water Creek and Clarks Fork Yellowstone River.)	29

LIST OF TABLES

Table		Page
1	Ground Truth Data Program for Aerial Photography and Imagery on Clarks Fork Yellowstone River.	10
2	Clarks Fork Yellowstone River Infrared Photography and Imagery Flights - Basic Data.	16
3	Clarks Fork Yellowstone River Infrared Photography and Thermal Imagery Flights - Suspended Sediment Data	17
4	Clarks Fork Yellowstone River Infrared Photography and Imagery Flights - Temperature Cross Sections.	18
5	Location and Discussion of Selected Areas near the Confluence of the Yellowstone River and the Clarks Fork Yellowstone River	31
6	Location and Discussion of Tributaries of the Clarks Fork Yellowstone River and Accompanying Sample Sites	32
7	Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.	84
8	Summary of Inflows with relative turbidity classifications . .	92

INTRODUCTION

Purpose of Study

This report presents the results of a cooperative study of sediment problems in the Clarks Fork Yellowstone River by the Bureau of Reclamation and Colorado State University. The basic purposes of the study were: (1) to locate the points at which sediment loads are discharged into the river, (2) to estimate the relative magnitude of sediment concentrations in the river and tributary flows, and (3) to show the usefulness of aerial remote sensing techniques (color infrared photography and thermal imagery) in monitoring and studying sediment movements in a river system.

Background

Historically, the Clarks Fork Yellowstone River, located in south-central Montana and northwestern Wyoming, has discharged heavy loads of sediment annually into the Yellowstone River. The transport of this material from the basin has destroyed much of the potential of the river for trout fishing and recreation, represents a substantial loss of top-soil to the agriculturists, and has created numerous problems for public water supplies. The soils, topography, rainfall pattern, land use, and irrigation practices of the basin are the principal causes for sediment in the river and its deposition in the stream channel.

In an effort to define sediment and siltation problems and their causes in the Clarks Fork Yellowstone River, the 1971 Montana State Legislature established the Clarks Fork Siltation Study Committee and charged it with the preparation of a report on its findings for the 1973 legislative session (1971 House Resolution No. 24). Composed of representatives from several state agencies, federal agencies, and various county and local organizations, the Committee began its investigation of the basin during the summer of 1971. In early discussions of investigative procedures, the use of remote sensing techniques to aid in the study was considered, and the Bureau of Reclamation agreed to support such an investigation as part of its participation in the program. This report is a result of that support.

This study of sediment in the Clarks Fork Yellowstone River was conducted primarily by personnel of the Civil Engineering Department of Colorado State University under contract and with assistance from the Bureau of Reclamation. The Upper Missouri Regional Office of the Bureau in Billings, Montana, provided a portion of the financial support for the project, supplied personnel to conduct the reconnaissance and ground-truth data programs in the basin, and assisted in the interpretation of the imagery and preparation of the report. The Engineering and Research Center in Denver, Colorado provided the balance of the financial support for the study and supplied personnel and equipment to aid in the interpretation of the remote sensing data. This report is a combined effort of Colorado State University and Bureau of Reclamation personnel.

Scope of the Investigation

To accomplish the basic purposes of the study, inflows of surface water to the Clarks Fork Yellowstone River, Rock Creek and a portion of Red Lodge Creek were located and identified. The inflows involved both perennial and intermittent tributaries to these rivers and irrigation return flows including drainage from high water table areas and canal wasteway flows.

Remote sensing provides the most practical method of obtaining data to achieve the above objectives. The data can be easily obtained and coverage of the entire area is accomplished in a relatively short period of time. Stereoscopic viewing of overlapping photographs assists the interpretation by providing topographic relief to delienate the small drainage areas, catchments, and watersheds.

Color infrared photography with 60% endlap for stereoscopic viewing and thermal infrared imagery were obtained for the rivers and adjacent flood plains shown in Figure 1. The photographs provided coverage of a strip of the flood plain approximately 1-1/2 miles wide for Red Lodge Creek, Rock Creek and the lower section of the Clarks Fork Yellowstone River. The coverage of the upper 36 miles of the Clarks Fork Yellowstone River provided a strip approximately 2-1/2 miles wide. Interpretation of the data was based upon and limited to this coverage.

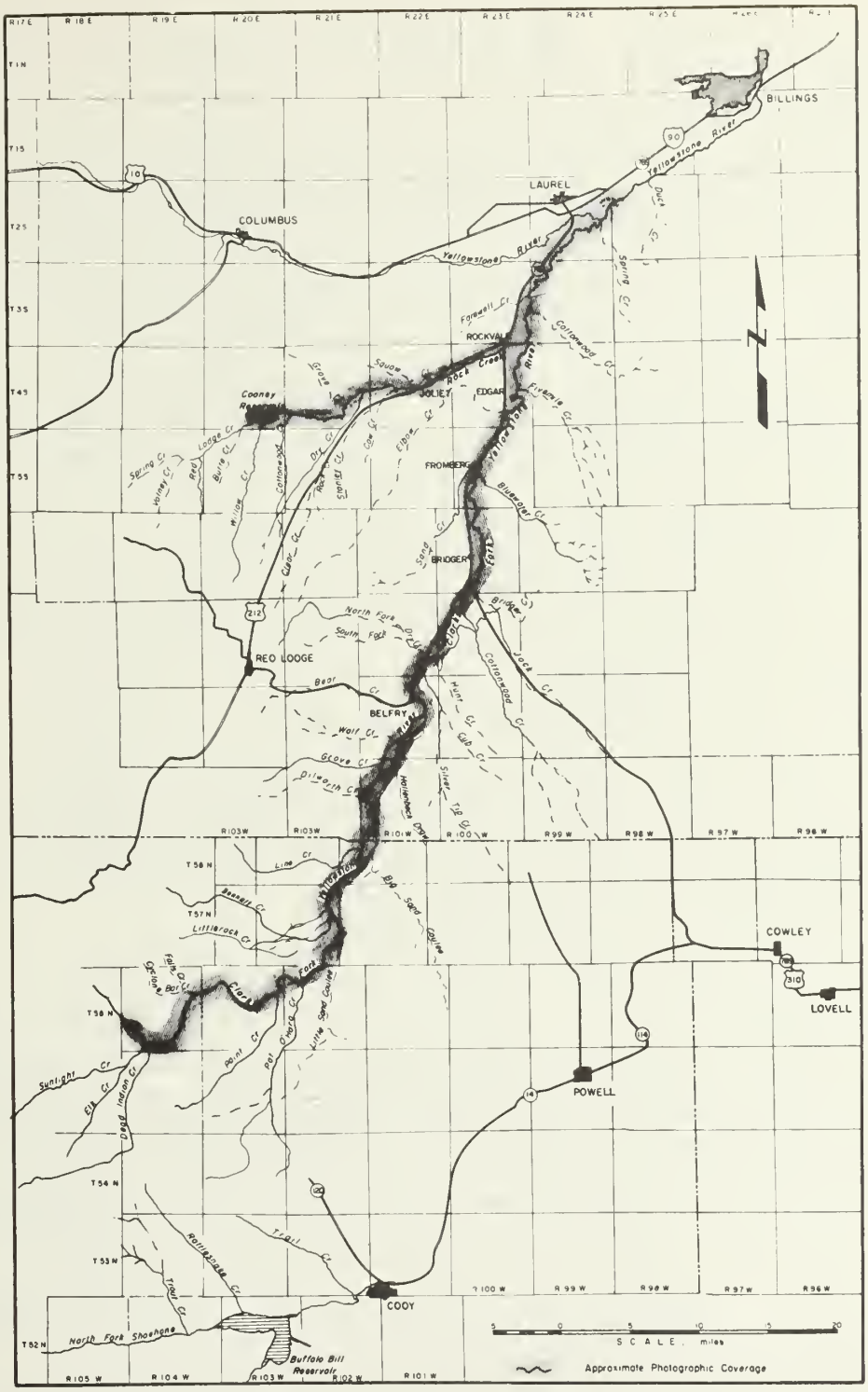


Figure 1 Location Map of the Clarks Fork Yellowstone River Remote Sensing Project

BASIN CONDITIONS

General Description

The Clarks Fork Yellowstone River is located in southcentral Montana and northwestern Wyoming. The river drains an area of approximately 2,783 square miles extending from the northeast corner of Yellowstone National Park northeastward to its confluence with the Yellowstone River near Laurel, Montana. The drainage basin includes about one-fourth of Park County, Wyoming, and most of Carbon County and small parts of Park, Stillwater, Big Horn, and Yellowstone Counties, Montana.

The major tributary of the Clarks Fork Yellowstone River is Rock Creek which has a drainage area of about 571 square miles. Other important tributaries are Sunlight Creek, Pat O'Hara Creek, and Big Sand Coulee in Wyoming, and Silvertip Creek, Bear Creek, and Cottonwood Creek in Montana. These streams, along with other tributaries, are shown on the Location Map of the Clarks Fork Yellowstone River, Figure 1.

The climate of the Clarks Fork Yellowstone River Basin is broadly classified as "continental" with several modifications resulting from the mountain-valley-plain configuration of the basin. Precipitation in the basin ranges from nearly 70 inches per year in some areas of the Absaroka Mountains to only 7 inches per year in some parts of the Clarks Fork Yellowstone River Valley. The areas of low precipitation are caused by a "rain shadow" effect from the high mountains to the west and the prevailing west to southwest wind pattern. In the mountains and during cold seasons of the year, most of the precipitation occurs as snow. The temperature range for the basin is also fairly large, with average annual temperatures varying from approximately 46°F near the mouth of the river to less than 40°F in the mountains near Red Lodge. Extreme temperatures of less than -40°F and more than 100°F occur occasionally in the basin.

Terrain Conditions

The Clarks Fork Yellowstone River Basin has a wide variety of physical features, beginning amoung the lofty peaks and high glaciated plateaus of the Absaroka Mountain Range and ending in the plains of the Yellowstone River Valley. The outstanding feature of the upper basin is the Beartooth Plateau, a barren, rocky mountain-mass dotted with numerous glacial lakes. Near its midpoint, the basin opens into a broad valley flanked by rolling foothills extending from the mountains to the Yellowstone River. Elevations of the basin range from 3,250 feet above mean sea level (MSL) at the mouth of the river to approximately 5,000 feet above MSL at the foot of the mountains to 12,600 feet above MSL at Silver Run Peak in the Beartooth Mountains.

With the ranges of elevation, topography, and precipitation present in the Clarks Fork Yellowstone River Basin, soil types are quite varied depending upon the location of sites in question. Generally, there are four main soil groups in the drainage area: (1) loamy well-drained soils

of the flood plains and narrow valleys; (2) deep, moderately deep, and shallow clayey soils of the shale and sandstone uplands; (3) deep and moderately deep loamy soils of the outwash terraces and fans; and (4) steep, shallow to deep loamy soils of the mountains. Flood plain and valley soils (loams and sandy loams) cover most of the low areas along the Clarks Fork Yellowstone River, Rock Creek, Red Lodge Creek, and other major tributaries. Land of the lower half of the basin above the flood plains are predominantly covered with the clayey soils of the shale and sandstone uplands. Outwash, terraces and alluvial fans along the Clarks Fork Yellowstone River and its tributaries are generally composed of loamy soils in the lower part of the basin and gravelly and stony, loam soils in the upper part of the basin. The upper portion of the drainage is covered with alpine soils, generally loam soils over limestone and shallow stony soils. More detailed information on soil types in the basin can be found in "Guidelines for Action, Beartooth Resource Conservation and Development Project, Montana," developed by Project Sponsors and assisted by U.S. Department of Agriculture and other Federal, State, and Local Agencies, 1970.

Land use in the Clarks Fork Basin is primarily agricultural with nearly 70 percent of the total land area devoted to cropland, pasture, and range. The following tabulation shows the distribution of land and its use in the basin:

Land Use	Percent of Total
Cropland	10
Pasture and Range	60
Forest	20
Alpine Tundra (above timberline)	10
	100

The major crops of the Clarks Fork Yellowstone River are small grains, corn, hay, sugar beets, and beans, Most of the small grain is produced on dry cropland under a summer fallow system with cultivation of about half of the land during each year. The other crops are grown on irrigated land along with a significant amount of pasture. The forested areas of the basin cover most of the mountain areas and parks of the foothills. Ponderosa pine and Rocky Mountain juniper cover the forested slopes of the mountains and drainageways, and Douglas fir and lodgepole pine, with some aspen in the low areas, occur in the foothill areas. The land above timberline in the Beartooth Plateau contains few trees and has an Alpine tundra-type vegetation.

Antecedent Weather Conditions for Remote Sensing Flights

During the 30 days prior to aerial remote sensing flights over the Clarks Fork Yellowstone River, weather conditions in the basin were generally cool and wet. Temperatures for the area were about five degrees below normal with an average of about 65°F. There were three significant rainstorms over most of the basin during the July 18 - August 18 period.

These storms and their precipitation were as follows:

Storm Period	Area of Basin	Precipitation
July 19-21	Entire basin with heaviest rainfall in western and northern portion of basin	1.3 inches
August 2-3	Entire basin with heaviest rainfall in northern portion of basin	1.0 inches
August 13-15	Light rain in eastern portion with heavy rainfall in western portion of basin	.5 inches

The August 13-15 storm deposited heavy amounts of rain in the southwestern portion of the basin on August 13 with some local flooding around Cooke City, Montana. It was estimated that flooding had subsided and runoff conditions were nearly normal at the time of the remote sensing flights which were made on August 18, 1972.

On the day of the aerial remote sensing flights, streamflow at U.S. Geological Survey gaging stations in the Clarks Fork Yellowstone River basin was as follows:

Station No.	Stream and Station	Flow (c.f.s.)
6207500	Clarks Fork Yellowstone River near Belfry	2,100
6208800	Clarks Fork Yellowstone River near Silesia	1,150
6209500	Rock Creek near Red Lodge	370
6211000	Red Lodge Creek above Cooney Reservoir	25
6212500	Red Lodge Creek below Cooney Reservoir	125

These flows are higher than normal for the basin at that time of the year, but they reflect the above-normal precipitation in the area for the entire summer. Flows of the main stem of the Clarks Fork Yellowstone River are reduced between Belfry and Silesia by irrigation diversions.

With these background conditions on the Clarks Fork Yellowstone River basin, the aerial remote sensing study of sediment problems in the river was conducted. The following sections describe that study and its results.

PROCEDURE

The basic procedure for the investigation of sediment in the Clarks Fork Yellowstone River involved four main phases of operation: (1) a reconnaissance of the basin to outline the problems to be investigated and general conditions of the area, (2) the ground-truth data program to collect physical information from the study area to relate to the photographs and imagery, (3) aerial flights to obtain the necessary color infrared photographs and thermal imagery to adequately cover the areas in question, and (4) the interpretation and analysis of results from these three data collection programs.

Reconnaissance

The first step in the study of sediment in the Clarks Fork Yellowstone River was several reconnaissance surveys of the basin to review the area of study, determine the nature of sediment problems in the river, and outline a plan of study for the proposed investigation. These surveys were conducted during the Fall of 1971 and the Spring and Summer of 1972 and involved both aerial and ground surveilance.

Aerial reconnaissance of the Clarks Fork Yellowstone River Basin was conducted by the Clarks Fork Silation Study Committee on September 13, 1972, and covered the main stem of the river and its tributaries in Montana. Results of that survey showed the river to be carrying a heavy sediment load at its mouth, but to be relatively clear at the Montana-Wyoming state line. There appeared to be two main reasons for this increase in sediment transport by the river: (1) sediment-laden inflows from tributary streams, and (2) irrigation return flows and wastes. Many subbasins of the Clarks Fork Yellowstone River drainage have highly erodible soils with only sparse vegetative cover. These conditions, along with rainfall patterns of the basin and current irrigation practices were observed over the eastern portion of the basin and appear to give the small drainages a high potential for contributing sediment to the river. At several different locations in the basin, irrigation facilities were observed to be discharging excess water into the Clarks Fork Yellowstone River and its tributaries. It appears that irrigation practices along these streams allow large volumes of water to be returned to the river which carry a heavy load of sediment. The aerial flights of this reconnaissance were most useful in observing sediment problems and conditions in the Clarks Fork Yellowstone River basin. To better define the relationship between these principles, several ground surveys were conducted.

Ground surveys of the Clarks Fork Yellowstone River basin, although limited, were directed toward observing soil and ground cover conditions in several subbasins of the drainage and observing irrigation practices in the flood plain of the river. Reconnaissance of several subbasins in the eastern portion of the basin (the area with least precipitation) revealed land whose soil was highly errosive, covered by only sparce vegetation, and cut by numerous gullies with severe vertical cutting. Observations of

irrigation practices in the basin showed a great deal of waste water being discharged into the river and its tributaries along with normal return flows. With the large area of the basin to be covered by this investigation and the amount of time involved with detailed ground surveys, an effort was made to find a suitable method for studying sediment problems in the whole Clarks Fork basin in a reasonable length of time.

From the information gained during the aerial and ground reconnaissance of the Clarks Fork basin and a review of present remote sensing technology, aerial infrared photography and thermal imagery were selected for this study of sediment problems in the river. A ground-truth data program was then established to gather the necessary information to adequately define relationships between physical conditions of the basin and the photographs and imagery.

Ground-Truth Data Program

The ground-truth data program for the aerial remote sensing study of sediment in the Clarks Fork Yellowstone River was designed to provide regularly spaced information on flow conditions of the river and its tributaries during the time when remote sensing flights were in progress. These data were obtained for the main stem of the river and its major tributaries from its confluence with the Yellowstone River near Laurel, Montana, to the mouth of Clarks Fork Yellowstone River Canyon in Wyoming. Figure 2 is a map of the basin showing the location of sampling stations for the program. Table 1 contains a detailed description of each sampling point and the data collected at that location.

The primary data collected during this ground-truth program were sediment samples, water temperatures, stream dimensions, and water depths at each sampling location. The sediment samples were analyzed for turbidity and sediment concentration. Results of the sampling program are shown in Tables 2 and 3.

In addition to these data, water temperature cross sections were also obtained for five locations along the main stem of the Clarks Fork Yellowstone River. These cross sections were used in the interpretation of thermal imagery obtained with the thermal infrared line scanner. The location of these cross sections are included in Figure 2 and Table 1 and the results of the temperature measurements are shown in Table 4.

The ground-truth data program was conducted simultaneously with the aerial flights to collect color infrared photographs and thermal imagery. The combination of these data are the nucleus of this study of sediment in the Clarks Fork Yellowstone River.

Airborne Data

The aerial photography for the Clarks Fork Yellowstone River, Red Lodge and Rock Creeks was obtained on August 18, 1972 between 10.24 am and 11:45 am Mountain Daylight Time. The weather over the sites was generally clear with a few localized scattered clouds in the vicinity

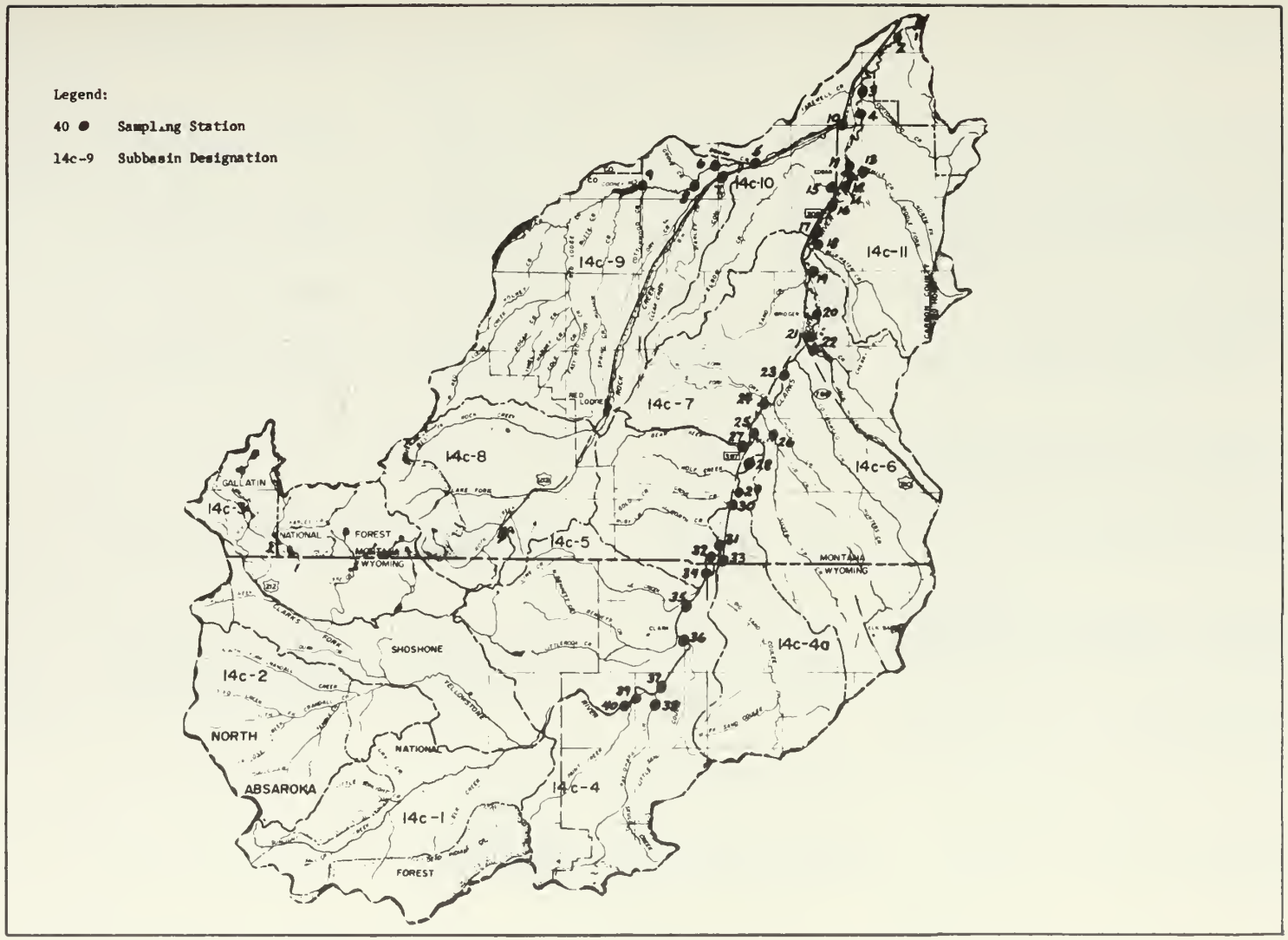


Figure 2 Drainage Area Map of the Clarks Fork Yellowstone River Showing Ground-Truth Collection Program for Aerial Remote Sensing Study

TABLE 1

GROUND TRUTH DATA PROGRAM
FOR AERIAL PHOTOGRAPHY AND IMAGERY
ON CLARKS FORK YELLOWSTONE RIVER

Sediment and Temperature Sites

Site No.	Location	Stream	Data	Description of Specific Sampling Site
YA	Sec.24, T2S, R24E	Yellowstone	Sediment & Temp	Sampling site at the first gravel bar above the confluence of the Yellowstone and Clarks Fork Rivers; 30 feet from the right bank.
YB	Sec.24, T2S, R24E	Yellowstone	Sediment & Temp	Sampling site below the confluence of the Yellowstone and Clarks Fork Rivers at the bend of the Yellowstone River where the road comes closest to the river; 20 ft. from the right bank.
1	Sec.24, T2S, R24E	Clarks Fork	Sediment & Temp	150 ft. downstream of bridge, 10 feet from left bank, near mouth.
2	Sec.28, T2S, R24E	Clarks Fork	Sediment & Temp	50 ft. upstream of bridge, 30 ft. from right bank.
3	Sec.24, T3S, R23E	Clarks Fork	Sediment & Temp	25 ft. off gravel bar, 125 ft. upstream of bridge, near Silesia.
4	Sec.25, T3S, R23E	Clarks Fork	Sediment & Temp	25 ft. from left bank, immediately below riffle just off corner of county road, below Rock Creek.
5 T-6	Sec.22, T4S, R22E	Rock Creek	Sediment & Temp Temp. X-Section	40 ft. upstream from railroad bridge, 40 ft. from right bank, southwest of Joliet.

TABLE 1

Sediment and Temperature Sites (continued)

Site No.	Location	Stream	Data	Description of Specific Sampling Site
6	Sec.24, T4S, R21E	Rock Creek	Sediment & Temp	Immediately downstream from Red Lodge Creek, 50 ft. from left bank.
7	Sec.25, T4S, R21E	Rock Creek	Sediment & Temp	75 ft. upstream from county road bridge west of Boyd, 10 ft. from left bank.
8	Sec.35, T4S, R21E	Red Lodge Creek	Sediment & Temp	5 ft. upstream from bridge on side road, 10 ft. from left bank.
9	Sec.36, T4S, R20E	Red Lodge Creek	Sediment & Temp	Below Cooney Dam, 50 ft. upstream from USGS gaging station, 10 ft. from right bank.
10	Sec. 2, T4S, R23E	Rock Creek	Sediment & Temp	100 ft. downstream from highway bridge, 25 ft. from left bank, near Rockvale.
11	Sec.14, T4S, R23E	Clarks Fork	Sediment & Temp	Due east of cemetery, downstream of Fivemile Creek, 30 ft. from right bank.
12	Sec.23, T4S, R23E	Clarks Fork	Sediment & Temp	20 ft. downstream of USGS gaging station, 25 ft. from right bank, east of Edgar.
13	Sec.24, T4S, R23E	Five Mile Creek	Sediment & Temp	20 ft. upstream of county road bridge, 3 ft. from left bank.
14	Sec.35, T4S, R23E	Clarks Fork	Sediment & Temp	Immediately downstream from Elbow Creek, in sharp turn of river, 15 ft. from left bank.
15	Sec.34, T4S, R23E	Elbow Creek	Sediment & Temp	5 ft. downstream from CMP, 8 ft. from left bank.

TABLE 1

Sediment and Temperature Sites (continued)

Site No.	Location	Stream	Data	Description of Specific Sampling Site
16	Sec. 3, T5S, R23E	Clarks Fork	Sediment & Temp	East of Highway, immediately downstream from 2 farm buildings and land leveler, 12 ft. from left bank.
17 T-1	Sec.16, T5S, R23E	Clarks Fork	Sediment & Temp Temp. X-Section	150 ft. upstream from bridge east of Fromberg, 165 ft. from right bank.
18	Sec.21, T5S, R23E	Bluewater Creek	Sediment & Temp	Taken from upstream side of county road bridge, south of Fromberg, 6 ft. from left bank.
19	Sec. 3, T6S, R23E	Clarks Fork	Sediment & Temp	50 ft. out (right) from downstream point of brushed island.
20 T-2	Sec.22, T6S, R23E	Clarks Fork	Sediment & Temp Temp. X-Section	100 ft. upstream from bridge east of Bridger, 20 ft. from right bank.
21	Sec.33, T6S, R23E	Clarks Fork	Sediment & Temp	125 ft. downstream from main highway 310 bridge, 35 ft. from right bank.
22	Sec. 4, T7S, R23E	Bridger Creek	Sediment & Temp	5 ft. downstream from county road bridge, 5 ft. from right bank.
23	Sec.18, T7S, R23E	Clarks Fork	Sediment & Temp	15 ft. downstream from county road bridge, 25 ft. from right bank.
24	Sec.25, T7S, R22E	Clarks Fork	Sediment & Temp	1/8 mile downstream from Dry Creek, 75 ft. upstream from main highway bridge, 15 ft. from left bank.

TABLE 1

Sediment and Temperature Sites (continued)

Site No.	Location	Stream	Data	Description of Specific Sampling Site
25 T-3	Sec.10, T8S, R22E	Clarks Fork	Sediment & Temp Temp. X-Section	Immediately upstream of main highway bridge, north of Belfry, 40 ft. from right bank.
26	Sec.12, T8S, R22E	Silver Tip Creek	Sediment & Temp	50 ft. upstream from USGS gaging station on Silver Tip Creek, 4 ft. from left bank.
27	Sec.11, T8S, R22E	Bear Creek	Sediment & Temp	Immediately upstream of highway bridge, north of Belfry, about 5 ft. from left bank.
28	Sec.27, T8S, R22E	Clarks Fork	Sediment & Temp	2.9 miles upstream from Belfry at main highway bridge, 30 ft. from right bank.
29	Sec.34, T8S, R22E	Clarks Fork	Sediment & Temp	3.9 miles upstream from Belfry at second main highway bridge, 15 ft. from right bank.
30	Sec. 4, T9S, R22E	Clarks Fork	Sediment & Temp	Immediately upstream from county road bridge, 15 ft. from right bank.
31 T-4	Sec.29, T9S, R22E	Clarks Fork	Sediment & Temp Temp. X-Section	150 ft. upstream from county road bridge, 20 ft. from left bank, below Sand Coulee.
32	Sec.32, T9S, R22E	Clarks Fork	Sediment & Temp	60 ft. downstream from county road bridge, above Big Sand Coulee, 12 ft. from right bank, above Wyoming line.
33	Sec.32, T9S, R22E	Big Sand Coulee	Sediment & Temp	1/4 mile upstream from confluence with Clarks Fork, at bridge near farm house, 10 ft. from right bank.

TABLE 1

Sediment and Temperature Sites (continued)

Site No.	Location	Stream	Data	Description of Specific Sampling Site
34	Sec.20, T58N, R101W	Clarks Fork	Sediment & Temp	Immediately downstream from county road bridge, 20 ft. from left bank, below Montana line.
35	Sec. 1, T57N, R102W	Clarks Fork	Sediment & Temp	Immediately downstream from bridge on paved road, 20 ft. from left bank, near F & WL HG.
36 T-5	Sec.30, T57N, R101W	Clarks Fork	Sediment & Temp Temp. X-Section	150 ft. downstream from main highway bridge, 40 ft. from right bank.
37	Sec. 8, T56N, R102W	Clarks Fork	Sediment & Temp	At old bridge location just downstream from Pat O'Hara Creek, 20 ft. from left bank.
38	Sec. 8, T56N, R102W	Pat O'Hara Creek	Sediment & Temp	Immediately downstream from small wooden bridge across Pat O'Hara Creek, 5 ft. from right bank.
39	Sec.12, T56N, R103W	Clarks Fork	Sediment & Temp	At foot bridge across Clarks Fork near farm houses, 50 ft. from left bank.
40	Sec.13, T56N, R103W	Clarks Fork	Sediment & Temp	About 1 mile downstream from river ford, 12 ft. from left bank, 4 miles east of Clarks Fork Canyon, last sample.

TABLE 1

(continued)

Soil Profiles

Site No.	Location	Data	Remarks
A-1	Sec.28 or 33, T7S, R23E	5'-Soil Profile	Near Cottonwood Creek
A-2	Sec.19 or 20, T8S, R23E	5'-Soil Profile	East of Belfry
A-3	Sec.33 or 34, T8S, R23E	5'-Soil Profile	On Cub Creek
A-4	Sec.21 or 22, T9S, R23E	5'-Soil Profile	Near Elk Basin, Oil Field
A-5	Sec.22 or 23, T9S, R22E	5'-Soil Profile	West of Silver Tip Creek
A-6	Sec. 9, T56N, R100W	5'-Soil Profile	In Wyoming, just off Cody Highway

TABLE 2

Clarks Fork Yellowstone River
Infrared Photography and Imagery Flights

Basic Data
October 18, 1972

Station No.	Stream	Time	Air Temp. (°F)	Water Temp. (°F)	Distance from Bank (ft)	Depth of water (ft)	Turbidity (JTU)
YA	Yellowstone	4:30 pm	71	71	30(R)	1.5	21
YB	Yellowstone	5:10 pm	-	72	20(R)	3.3	39
1	Clarks Fork	4:15 pm	71	72	10(L)	3.0	75
2	Clarks Fork	3:55 pm	72	70	30(R)	1.5	73
3	Clarks Fork	3:20 pm	72	70	25	2.0	69
4	Clarks Fork	3:35 pm	71	70	25(L)	2.2	65
5	Rock Creek	1:35 pm	74	68	40(R)	1.5	10
6	Rock Creek	1:55 pm	75	68	50(L)	1.8	9
7	Rock Creek	2:15 pm	75	68	10(L)	2.5	5
8	Red Lodge Cr.	2:30 pm	72	70	10(L)	2.5	11
9	Red Lodge Cr.	2:55 pm	72	66	10(R)	2.2	7
10	Rock Creek	1:15 pm	73	70	25(C)	2.3	11
11	Clarks Fork	12:55 pm	72	67	30(R)	1.5	70
12	Clarks Fork	12:15 pm	75	66	25(R)	3.2	66
13	Five Mile Cr.	12:10 pm	77	68	3(C)	1.0	89
14	Clarks Fork	12:05 pm	70	65	15(C)	2.5	65
15	Elbow Cr.	11:50 am	70	65	7(C)	2.0	95
16	Clarks Fork	11:40 am	68	64	12(R)	3.2	64
17	Clarks Fork	10:40 am	69	64	165(L)	2.5	62
18	Bluewater Cr.	10:18 am	72	64	6(C)	1.8	72
19	Clarks Fork	9:45 am	70	62	50(R)	2.3	54
20R	Clarks Fork	8:40 am	60	61	20(R)	2.3	53
20L	Clarks Fork	9:15 am	60	62	38(L)	2.0	57
21	Clarks Fork	7:25 am	60	60	35(R)	2.5	53
22	Bridger Cr.	7:10 am	62	60	5(C)	1.0	57
23	Clarks Fork	6:55 am	59	60	25(R)	2.0	57
24	Clarks Fork	6:35 am	56	62	15(L)	2.0	75
25	Clarks Fork	6:05 am	54	60	40(R)	2.8	45
26	Silver Tip Cr.	5:55 am	58	60	3.5(C)	0.25	295
27	Bear Cr.	6:25 am	54	59	5(C)	0.45	100
28	Clarks Fork	6:40 am	53	59	30(R)	2.3	42
29	Clarks Fork	6:50 am	55	59	15(R)	2.6	42
30	Clarks Fork	7:00 am	56	59	15(R)	2.2	40
31	Clarks Fork	7:30 am	56	57	20(L)	2.3	46
32	Clarks Fork	8:00 am	57	57	12(R)	4.0	51
33	Big Sand Coulee	7:15 am	58	58	10(C)	1.0	57
34	Clarks Fork	8:10 am	58	57	20(L)	2.5	53
35	Clarks Fork	8:30 am	58	55	20(L)	2.7	37
36	Clarks Fork	8:50 am	66	57	40(R)	2.0	44
37	Clarks Fork	9:45 am	66	59	20(L)	2.7	36
38	Pat O'Hara Cr.	9:30 am	68	60	5(C)	0.8	23
39	Clarks Fork	10:00 am	68	59	50(L)	2.6	32
40	Clarks Fork	10:15 am	72	59	12(L)	2.7	33

TABLE 3

Clarks Fork Yellowstone River
Infrared Photography and Thermal Imagery Flights

Suspended Sediment Data

October 18, 1972

Station No.	Suspended Sediment Concentration (ppm)	Station No.	Suspended Sediment Concentration (ppm)
YA	35	21	67
YB	85	22	109
1	145	23	130
2	162	24	158
3	152	25	98
4	140	26	676
5	11	27	252
6	11	28	84
7	77	29	87
8	15	30	74
9	4	31	114
10	7	32	80
11	142	33	116
12	113	34	124
13	206	35	80
14	173	36	98
15	879	37	52
16	129	38	24
17	119	39	7
18	180	40	71
19	129		
20R	249		
20L	124		

TABLE 4

Clarks Fork Yellowstone River
Infrared Photography and Imagery Flights

Temperature Cross Sections
October 18, 1972

Station No.	Time	Approx. Width (ft)	Air Temp. (°F)	Distance from Bank (ft)	Depth (ft)	Temp. at 6" (°F)
17, T-1	10:50 am	180	69	0(L)	0	-
				10(L)	0.5	63
				20(L)	1.0	64
				30(L)	1.6	64
				40(L)	2.2	64
				50(L)	2.5	64
				60(L)	2.0	64
				70(L)	1.6	64
				80(L)	1.4	64
				90(L)	1.5	64
				100(L)	2.3	64
				110(L)	2.6	64
				120(L)	2.8	64
				130(L)	2.5	64
				140(L)	1.5	64
				150(L)	2.3	64
				160(L)	2.5	64
				170(L)	2.4	64
				180(L)	0	-
20, T-2	9:00 am	240	60	0(R)	0	-
				10(R)	2.0	61
				20(R)	2.0	61
				30(R)	1.8	61
				40(R)	1.5	61
				50(R)	1.5	61
				60(R)	1.2	61
				70(R)	1.0	61
				80(R)	1.0	61
				90(R)	1.0	61
				100(R)	.9	61
				110(R)	1.1	61
				120(R)	1.4	61
				130(R)	1.6	61
				140(R)	1.6	61
				150(R)	1.0	61
				160(R)	1.5	61
				170(R)	2.0	61
				180(R)	2.5	61
				186(R)	2.2	61
				0(L)	0	-
				10(L)	1.5	62
				20(L)	2.0	62
				30(L)	2.0	62
				40(L)	2.0	62
				50(L)	2.6	61
				53(L)	2.2	62

TABLE 4 (continued)

Temperature Cross Sections (continued)

Station No.	Time	Approx. Width (ft)	Air Temp. (°F)	Distance from Bank (ft)	Depth (ft)	Temp. at 6" (°F)
25, T-3	11:45 am	200	85	0(L)	0	-
				20(L)	2.1	63
				40(L)	3.0	63
				60(L)	3.2	63
				70(L)	3.6	63
				90(R)	2.7	63
				80(R)	3.1	63
				60(R)	2.6	63
				40(R)	1.5	63
				20(R)	1.0	63
				0(R)	0	-
31, T-4	11:00 am	75	81	0(L)	0	-
				10(L)	1.7	61
				30(L)	3.0	60
				20(R)	2.9	61
				10(R)	1.6	61
				0(R)	0	-
36, T-5	9:15 am	205	66	0(R)	0	-
				15(R)	1.7	57
				35(R)	2.0	57
				55(R)	2.5	57
				75(R)	2.5	58
				100(R)	2.6	58
				120(R)	3.1	58
				140(R)	3.1	58
				160(R)	2.7	58
				180(R)	2.8	58
				200(R)	1.6	58
				205(R)	0	-

of the confluence of the Clarks Fork Yellowstone River and the Yellowstone River. Photographs of the Clarks Fork Yellowstone River from the confluence with the Yellowstone River to the mouth of the canyon were obtained at approximately 5,000 feet above the mean terrain providing a photograph scale of approximately 1:10,000. The Clarks Fork Yellowstone River above the mouth of the canyon were obtained at an altitude of approximately 8,500 feet above the mean terrain providing a photograph scale of approximately 1:17,000. Photographs of Rock Creek and Red Lodge Creek were also obtained at a scale of approximately 1:10,000.

The photography was obtained with a Wild RC-8 Precision Mapping Camera using a 6 inch Universal Aviogon Lens. The RC-8 system includes filters, a NF 1 navigation sight, and a PAV 2 Universal Mount. The camera system produces a 9 inch x 9 inch photograph with minimum distortion and high resolution.

Kodak Aerochrome Infrared Film 2443 was exposed in the Wild RC-8 camera. It was processed to a positive transparency for analysis on a light table. The color infrared film has three layers of emulsion which when exposed respond to wavelengths corresponding to the green, red and the photograph infrared portions of the electromagnetic spectrum. Through a subtractive color process this film produces a "false" color image of the scene in which green appears blue, red appears green, and photographic infrared appears red.

Thermal infrared imagery of the Clarks Fork Yellowstone River, Rock Creek and Red Lodge Creek were also obtained for this study. The U.S. Department of Agriculture, Forest Service, Missoula, Montana was subcontracted to fly these sections of the rivers to obtain the thermal infrared imagery. The imagery was obtained on August 18, 1972 between 6:20 am and 7:10 am Mountain Daylight Time using a modified Texas Instruments RS-7 Scanner flown in a Beechcraft King Air aircraft at an altitude of approximately 3,000 feet above the mean terrain. The imagery was recorded on a three and one half inch wide strip film format. A negative transparency is produced on which warmer temperatures appear dark and cool temperatures appear light; when the positive transparency or positive print is produced, warmer temperatures are lighter and cooler temperatures are darker.

Data Analysis

The primary data analysis was accomplished by viewing both the color infrared positive transparency film and the thermal infrared imagery (processed to a negative transparency) on a light table. A Bausch and Lomb Zoom 240 Stereoscope mounted on a Richards Corporation dual strand light table was used to provide a detailed view. This unit is designed so adjacent photographs in roll format can be viewed stereoscopically or a single photograph can be viewed through a mono-vision, zoom-magnification

The interpreter scanned the photographs and imagery to locate points of inflow which were detectable as sediment plumes or temperature plumes in the river. Drainage patterns delineated by vegetation and/or

erosion areas identified other potential sources of sediment inflow. The most obvious locations were found and described by this scanning process. Stereo-pairs of photography then were viewed to identify drainage relief which was not obvious in the initial overview. Magnification of the image through the stereoscope assisted the interpreter to view characteristics at the bank line and in the gully and ditch bottoms necessary to determine if they contained water. Ditches, gullies, and tributaries were traced through their respective drainage basins to the limits of the photographic coverage. The color of the water was used to determine the amount of suspended sediment concentration of the inflow relative to the river.

Photography and Radiation Principles

Radiation is one of the three principle processes of energy transfer. Visible light, heat, radio waves, and X-rays are some of the energy forms transmitted by the radiation process. These forms of energy are similar and are grouped under a single classification of electromagnetic radiation. All forms of electromagnetic radiation travel in straight lines at the speed of light and obey similar laws of reflection, refraction, diffraction, and polarization. They can be focused to record images on sensitized paper or film or transduced to provide an electrical signal which may be recorded.

Three distinct portions of the electromagnetic spectrum are of interest in this remote sensing study. These three portions are:

1) The visible portion having wavelengths from 0.4 micrometers to 0.7 micrometers.

2) The photographic infrared portion from 0.7 micrometers to 0.9 micrometers.

3) The thermal infrared portion from 8 micrometers to 14 micrometers.

Color infrared film is sensitive to electromagnetic energy having wavelengths from 0.4 micrometers to 0.9 micrometers. It contains three layers of emulsion which are sensitized to respond to wavelength bands corresponding to green, red, and the photographic infrared. All three emulsions are sensitive to blue light and therefore a minus-blue filter is used to eliminate the wavelengths below 0.5 micrometers. Through a subtractive color process this film produces a "false" color image of the scene in which green appears blue, red appears green, and photographic infrared appears red. The infrared sensitive color film was originally designed for military applications of camouflage detection. It has been used extensively for forest surveys to identify diseased foliage. More recently the film has been used extensively by Colorado State University for river studies. The color infrared film has been found to be very effective for monitoring sediment transport processes in rivers. Small changes in suspended material concentrations in water change the reflectance characteristics singificantly in the wavelengths recorded on the color infrared film.

The longer wavelength portion of the electromagnetic spectrum from 8 to 14 micrometers is emitted or thermal radiation. To record this portion of the spectrum the emitted energy must be focused on a special detector and transduced to an electrical signal. The transduced signal is used to modulate a light source which in turn is used to expose a black and white film strip. The grey level of the resulting imagery is proportional to the emissivity and temperature of the object.

The grey tones, on the thermal imagery, between black and white, give a qualitative indication of water surface temperatures. The grey tones of other terrain scenes are recorded in accordance with the value of their corresponding emissivity as well as temperature. Water has an emissivity close to unity, but soil and vegetation may have a range of values less than unity.

INTERPRETATION

The following interpretive keys were used to identify the inflows, tributaries, and potential tributaries which would be sources of sediment for the river.

1) Color - Color is the primary key to identifying sources of inflow into the river. Clear water inflows appear dark blue (black in the cases of deep water) on color infrared film. Changes of concentrations of suspended material change the color of the water to a blue, blue grey or powder blue approaching a light blue with increased suspended sediment concentrations. Green vegetation which appears a bright red on color infrared film is also a key for identifying ditches or potential drainage ways.

2) Topographic Relief - Stereoscopic viewing of stereo-pairs of photographs provides the three-dimensional relief necessary to identify small catchments and erosion patterns and to judge the slope and topography related to agricultural lands.

3) Pattern, Shape, and Texture - Farmlands and row crops are readily identified by the patterns, alignments, colors and textures. Upland areas have color and erosion patterns and shapes which can be identified readily.

4) Temperature/Emissivity - The thermal infrared imagery is interpreted based upon a judgement of grey levels and the temperature/emissivity characteristics of the scene.

Color infrared photography effectively detects small changes in low concentrations of suspended particles in water and enhances the change by a color difference. Sufficient research has not been accomplished to identify if the cause of the color difference is due to the change in turbidity level or suspended solids concentrations. However, for this study it was found that the suspended solids concentration and the turbidity level appear to vary linearly within the normal scatter associated with field sampling procedures. The relationships between suspended solids concentration in parts per million (ppm) and turbidity levels in Jackson turbidity units (JTU) is shown in Figure 3. The data for Figure 3 was obtained from samples taken the day of the overflight.

Examples of the Clarks Fork Yellowstone River and several tributary inflows are given in the following illustrations:

Figure 4 - is the confluence of the Clarks Fork Yellowstone River and the Yellowstone River. Samples of suspended sediment indicated 35 ppm at Point YA upstream from the confluence on the Yellowstone; 85 ppm at Point YB downstream from the confluence, and 145 ppm at Point 1 on the Clarks Fork Yellowstone River upstream from the confluence. The higher sediment concentration is clearly deliniated by the lighter,

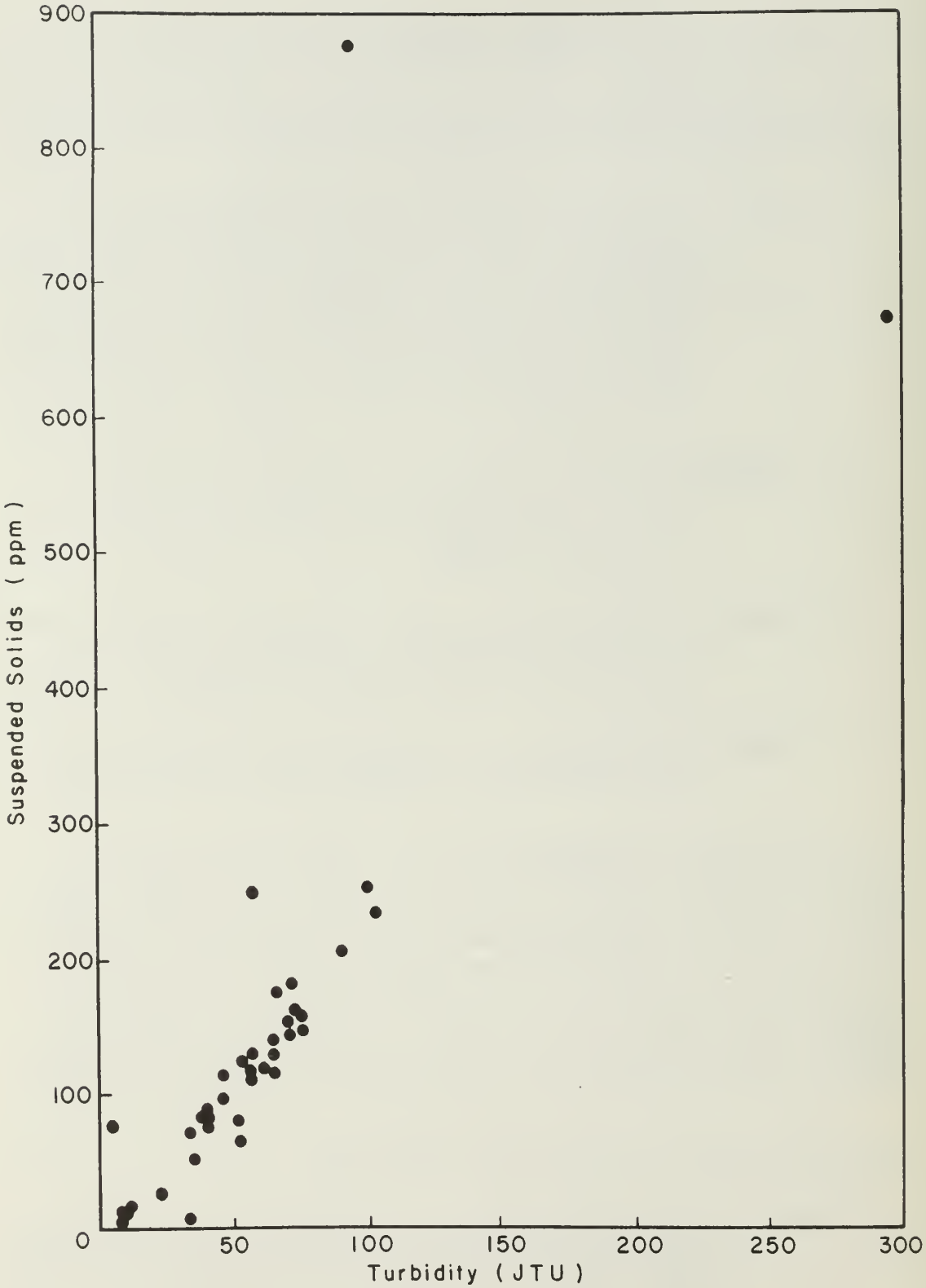


Figure 3 Relationship of Suspended Solids in Parts Per Million (ppm) and Turbidity in Jackson Turbidity Units (JTU)

Figure 4. Confluence of the Clarks Fork Yellowstone River and the Yellowstone River.

Sampling Site	Suspended Sediment Concentration (PPM)	Turbidity (JTU)
YA	35	21
YB	85	39
1	145	75

blue-grey color of the Clarks Fork Yellowstone River versus the darker blue of the Yellowstone River. Little mixing of the river waters occurs immediately downstream from the confluence as can be seen from the distinct plume. The suspended sediment sample obtained at Point YB was in the mixing zone or plume of the Clarks Fork Yellowstone River waters.

Figure 5 - shows the terrain in the vicinity of the confluence of Dry Creek and the Clarks Fork Yellowstone River. This area is typical of the terrain between the confluence of the Clarks Fork Yellowstone River and the Yellowstone River and mouth of the canyon. Depicted in the photograph are farmlands in the flood plain (A), the clayey-sandstone uplands (B), a highway (C), an irrigation diversion dam (D), the irrigation canal (E), and Dry Creek (F).

Figure 6 - is the confluence of Rock Creek and the Clarks Fork Yellowstone River. Rock Creek has a lower sediment concentration than the Clarks Fork. The relatively clear water of Rock Creek stands out as a dark blue (black) color; the Clarks Fork is a blue-grey color on this color infrared enlargement.

Figure 7 - shows a color infrared photograph of the confluence of Bennett Creek and the Clarks Fork Yellowstone River. The water in Bennett Creek has a lower sediment concentration than the Clarks Fork.

Figure 8 - is the thermal infrared imagery of the area that corresponds to the confluence shown on Figure 7. Bennett Creek is designated "BC", and the Clarks Fork Yellowstone River "CF" in Figure 8. The colder water of Bennett Creek, the plume and mixing zone, are clearly identified by the darker tone on the imagery. The plume can be observed on the imagery for approximately 1,500 feet downstream from the confluence. The temperature of the water in Bennett Creek was not measured, but the temperature of the Clarks Fork Yellowstone River approximately one third mile upstream from the confluence was 57°F and at point approximately one half mile downstream was 55°F. The downstream measurement was obtained at a point 20 feet from the left bank and was probably in the cold water plume.

Figure 9 - shows the thermal infrared imagery obtained in the vicinity of Fromberg, Montana (FR). Bluewater Creek (BW) enters the Clarks Fork Yellowstone River (CF) near this town and shows up as the white line meandering through the irrigated fields on the right bank. The temperatures of the two streams are approximately equal (64°F) at their confluence and this is indicated by the same level of grey on the imagery. The imagery was obtained at approximately 6:50 am Mountain Daylight Time.

Figure 5. Confluence of Dry Creek and the Clarks Fork Yellowstone River and Environs.

Figure 6. Confluence of Rock Creek and Clarks Fork Yellowstone River.

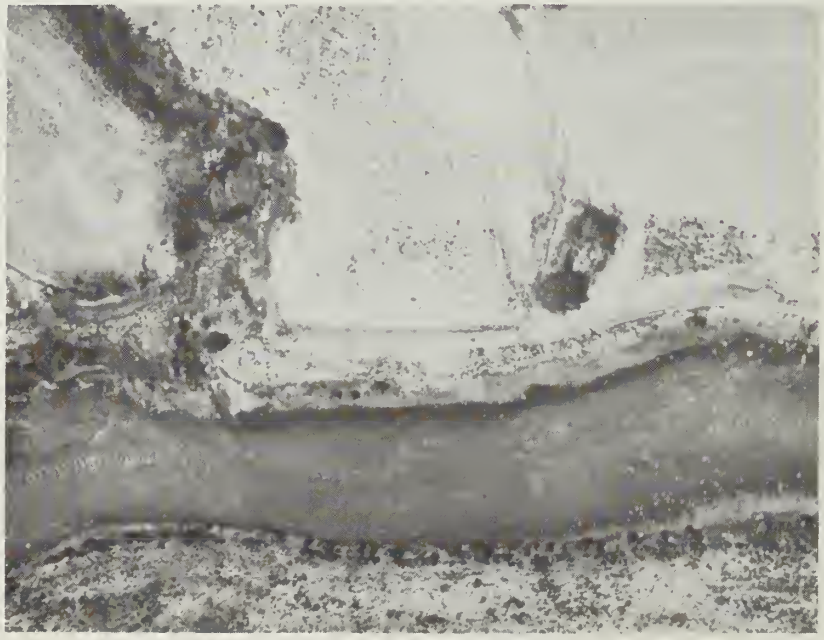


Figure 7. Confluence of Bennett Creek and Clarks Fork Yellowstone River.

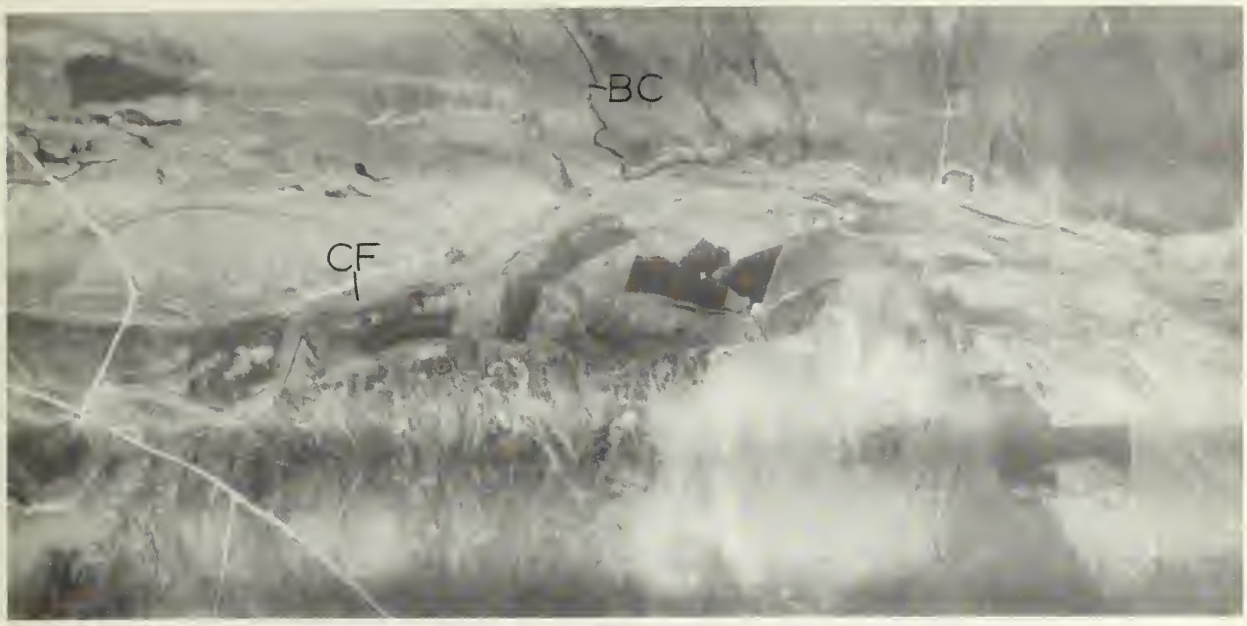


Figure 8. Thermal Infrared Imagery of confluence of Bennett Creek and Clarks Fork Yellowstone River.

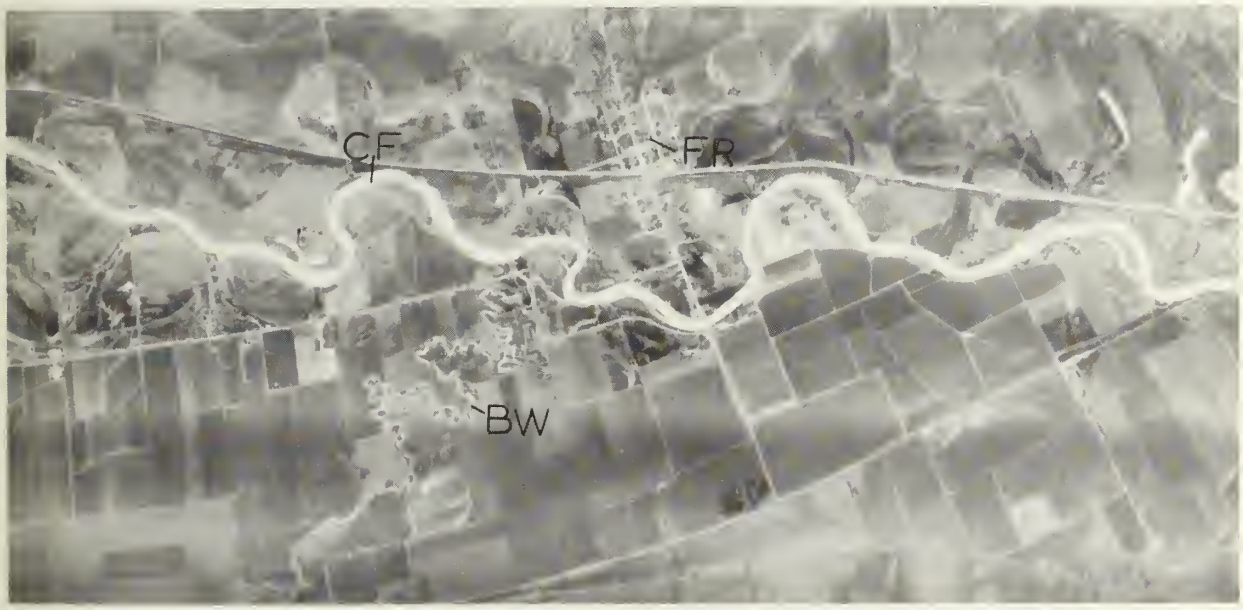


Figure 9. Thermal Infrared Imagery of the vicinity of Fromberg, Montana (showing Blue Water Creek and Clarks Fork Yellowstone River).

Primary interpretation of both the color infrared photography and the thermal infrared imagery was based on the interpreter's visual acuity. The inflows to the rivers were identified using the interpretative keys. The interpreter identified the inflow or potential inflow and described the relative suspended material concentration within the field of view provided by the photograph.

A description of the confluence of the Clarks Fork Yellowstone River and the Yellowstone River and the sampling sites above and below the confluence are given in Table 5. All tributaries and potential tributaries to the Clarks Fork Yellowstone River are identified in Table 6. Rock Creek, Red Lodge Creek and their tributaries are identified in Table 7.

The inflows are tabulated in an upstream order starting at the confluence of the Clarks Fork Yellowstone River and the Yellowstone River, the confluence of Rock Creek and the Clarks Fork Yellowstone River and the confluence of Red Lodge Creek with Rock Creek and proceeding to the confluence of Rock Creek. The points of inflow of the tributaries are located according to township, range, and section. A notation is made to indicate if the tributary had water in it or if it was dry at the time the photographs were taken. The photo number and quadrant number refers to the frame number of the 9 inch x 9 inch color infrared transparent photograph and the quadrant of the photograph the stream or tributary enters the river. The quadrants are assigned in a counter clockwise direction when the photograph is oriented with the clock and altimeter on the original film roll located on the observers right; quadrant 1 is upper right. A brief discription of the tributary inflow and, in some cases, the area it drains is provided. In cases where the discharge is small, no discription of the sediment concentration is given. Samples of water were collected at several locations on the day of the overflight. These samples were analysed for turbidity and suspended sediment concentrations (See Tables 2 & 3). Air and water temperature and water depth at sampling points also were recorded (See Tables 3 & 4). The results of the analysis of these samples are tabulated with the nearest tributary inflow.

TABLE 5 - Location and Discussion of Selected Areas near the Confluence of the Yellowstone River and the Clarks Fork Yellowstone River.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
Y1	2S	24E	24		CF2	W	71	71	1.5	35	21	YA	7801	Sampling Site YA at the first gravel bar above the confluence of the Yellowstone and Clarks Fork Rivers; 30 feet from the right bank. (See Figure 4)
Y2	2S	24E	24		CF2	W	-	72	3.3	.85	39	YB	7801	Sampling Site YB below the confluence of the Yellowstone and Clarks Fork River at the bend of the Yellowstone River, where the road comes closest to the river: 20 feet from the right bank. (See Figure 4)
Y3	2S	24E	24		CF2	W							7801	Yellowstone - Clarks Fork Confluence, The sediment laden water of the Clarks Fork can be easily delineated from the clearer water of the Yellowstone. This is indicated by the darker blue color of the Yellowstone as compared to the grey - blue color of the Clarks Fork. Thermal imagery shows no significant temperature difference between the two rivers. (See Figure 4)

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
1	2S	24E	24	R	CF2	W							7801 IV	There are deposits at the mouth of Spring Creek which is on the right side of the river opposite sampling site #1. The mouth of the creek is about 200 feet downstream from highway bridge. Flow rate is very small. The water is obscured partially bv willow growth. Pooled water can be seen between essentially dry sections of the stream bed. (See Figure 4)
1A	2S	24E	24		CF2	W	71	72	30	145	75	1	7801	Sampling Site: 150 feet downstream of bridge, 10 feet from left bank. (See "C" in Figure 4)
2	2S	24E	21	R	CF3	D							7800 III	Drainage patterns converge and enter the flood plain from the right bank. These emanate from hay fields.
3	2S	24E	22	R	CF3	W							7799 Mid	A creek enters the river about 1 1/4 miles downstream of a bridge and appears to have about the same sediment concentration as the river. Its flow rate increases as it approaches the river due to a diversion canal discharging into the stream for return to the river. Algae is evident in some of the stagnant back waters.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
4	2S	24E	27	L	CF4-3	W							7798 I	A straight line ditch enters the river about 3/4 mile below the bridge. This ditch is the main drainage ditch for dewatering a high water table area. Relatively clear water is being discharged to the river.
5	2S	24E	27	L	CF4	W							7797 I	Relatively clear ground water return from the high water table is evident in the old river channel. There is some algae in the backwater.
5A	2S	24E	28		CF4	W	72	70	1.5	162	73	2	7796	Sampling Site: 50 feet upstream of bridge, 30 feet from right bank.
5B	2S	24E	33	L	CF5	D							7795 I	A ground water drainage ditch enters at the outside of bend of the river on the left bank.
6	2S	24E	33	L	CF5	W							7795 I-II	There is a groundwater drainage ditch next to road, near the farm house. The water is relatively clear.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
7	3S	24E	5	L	CF6	W							7793 I	This groundwater drainage ditch overlays the meander channel of the river. The return flow is relatively clear.
8	3S	24E	8	L	CF7	D							7792 IV	A dry ditch intersects the river above a sand bar.
9	3S	24E	8	R	CF7	W							7791 IV	The river divides in this area. The left channel is the larger of the two.
10	3S	24E	7	R	CF7	D							7790 IV	There are drainage patterns (dry) intersecting the right channel downstream from the storage bins and animal pens. A small dam has been constructed on the major drainage arm and a small pool of turbid water can be seen behind the dam.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
11	3S	R24E	7	L	CF7-8	W							7790 I	There is flow coming into the left channel from the old meander channel. At this time of the year, the flow would be primarily groundwater return. This flow appears to have about the same sediment concentration as the river.
12	3S	K23E	13	L	CF8	W							7788 I	Farewell Creek enters the river here. Irrigation water is diverted into and out of this creek. There is no appreciable difference in sediment concentration at the mouth from the creek.
13	3S	23E	24		CF9	W	72	70	2.0	152	69	3	7787	Sampling Site: 25 feet off gravel bar, 125 feet upstream of bridge.
14	3S	23E	24	R	CF9	W							7787 I	Cottonwood Creek enters river approximately 1100 feet upstream from sampling site #3. There is no evident sediment difference at the mouth. The creek drains primarily uncultivated land except for a small band of irrigated cropland near the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
15	3S	23E	25	L	CF9 10	W							7786 I	Groundwater return flow enters the river at 3 points on the outside of the bend of the river. The water is relatively clear. The return water passes through several cattle pens which were empty at the time of the photograph. Standing water between the creek and the river is evidence of the high water table in this area.
16	3S	23E	25		CF10	W	71	70	2.2	140	65	4	7786	Sampling Site: 25 feet from left bank immediately below riffle just off corner of county road.
17	3S	23E	25	L	CF10	W							7785 IV	Groundwater drainage ditches enter at two points on the straight portion of river. The upstream one is flowing clearer than the river. The downstream ditch does not appear to be contributing to the river at this time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
18	3S	23E	25	L	CF10	W							7785 III	Vegetation and topography pattern indicate groundwater return entering at the large island. A small amount of return flow can be detected.
19	3S	23E	36	L	CF11	W							7784 IV	Groundwater return flow enters about 1400 feet downstream of the Rock Creek confluence with the Clarks Fork. This stream originates in the high water area between Rock Creek and the Clarks Fork. The water is relatively clear.
20	3S	23E	36	R	CF11	D							7784 IV	Dry drainage patterns on this bank. The drainage area is barren except for trees and brush in the bottom of the gullies.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
21	3S	23E	36	R	CF11	D							7595 II	Drainage patterns converge and intersect river, approximately 900 feet downstream from confluence of Rock Creek and Clarks Fork on the right bank.
22	3S	23E	36	L	CF11	W							7595 II	Rock Creek is very clear with a low sediment concentration. The plume boundary is clearly delineated by the nearly black color of Rock Creek and the very light blue color of the Clarks Fork. The thermal imagery shows Rock Creek to be the cooler of the two. (See Figure 6)
23	3S	23E	36	L	CF11	W							7595 I	Two ground water drainages enter the Clarks Fork near a small bar. One enters near the upstream end of the bar and the other enters approximately 500 feet below the bar. The return water is relatively clear. There is more flow in the upstream drainage.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
24	4S	23E	1	R	CF12	D							7596 I	A small dry creek enters the river from the right bank. There is also a dry ditch approximately 600 feet upstream from the creek.
25	4S	23E	12	R	CF12	W							7598 II	A ditch with heavy vegetation cover intersects the river on the outside of a very sharp bend to the left. This is irrigation waste water returned to the river. There is no flow at the time of the photograph.
26	4S	23E	12	L	CF12	W							7598 III	Clear water enters the river about 200 feet upstream of point where river runs parallel to and very near railroad track. This comes from across the tract from a very wet swamp and is probably the result of irrigation drainage.
27	4S	23E	12	R	CF13	W							7598 Mid	Flow comes out of old oxbow but there are no color differences in the river at the point of intersection. Irrigation is the source of this flow.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
28	4S	23E	14	L	CF13	W							7599 III	Ground water return flow enters from an old meander loop near the left bank. A drainage ditch also enters at approximately the same location. Both have clear water in them.
28A	4S	23E	14		CF13	W	72	67	1.5	142	70	11	7599	Sampling Site: Due east of cemetary downstream of Fivemile Creek, 30 feet from right bank.
29	4S	23E	14	L	CF13 14	W							7600 III-IV	Irrigation return is ponding and then returning to the river as two basic tributaries on left bank. The return water presently is relatively clear.
30	4S	23E	24	R	CF14	W	77	68	1.0	206	89	13	7601 II	Fivemile Creek intersects the river nearly tangentially on the right bank now the beginning of a bend to the left. It originates in the clayey soils of the shale and sandstone uplands and then flows through a broad band of cultivated farm land in the floodplain and irrigated terrace areas. This creek is carrying a higher sediment concentration than the river. The plume can be seen for nearly 400 feet downstream. Sampling Site: 20 feet upstream of county road bridge, 3 feet from left bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
31	4S	23E	24	L	CF14	W							7601 IV	Groundwater return flow enters just downstream of triangular shaped ponds. Return water is clearer than the river.
32	4S	23E	24	L	CF14	W							7602 III	Groundwater return flow enters the river about 800 feet downstream from the bridge. This return water is relatively clear.
33	4S	23E	24		CF15	W	75	66	3.2	113	66	12	7601	Sampling Site: 20 feet downstream of USGS gaging station which is at the bridge, 25 feet from right bank.
34	4S	23E	25	R	CF15	W							7603 II	A network of gullies on the right bank intersects the river on the outside of the bend. The two major inflow points are approximately 800 feet apart. The gullies originate on the clayey shale uplands. Excessive gully erosion is evident. Such areas produce large quantities of sediment during runoff periods. There is also groundwater return flowing through the point bar. The return flow is clearer than the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
35	4S	23E	25	R	CF15	W							7603 II	Flow from cut-off oxbow is clearer than the river. There is groundwater return flow entering this oxbow just upstream of Edgar.
36	4S	23E	35	L	CF16	W	70	65	2.5	173	65	14	7605	Sampling Site: immediately downstream from Elbow Creek, in sharp turn in river, 15 feet from left bank.
37	4S	23E	34	L	CF16	W	70	65	2.0	879	95	15	7605 III	Elbow Creek enters the river from the left bank. It has a higher sediment concentration than the river. It originates in the uplands and passes through the broad belt of irrigated farm land near the river. Sampling Site: 5 feet downstream from corregated metal pipe, 8 feet from left bank.
38	4S	23E	35	L	CF16	W							7605 IV	A creek enters the river approximately 1700 feet upstream from the mouth of Elbow Creek. It appears to carry a higher sediment concentration than either Elbow Creek or the Clarks Fork River.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
39	4S	23E	35	L	CF16	W							7606 III	A ditch carrying irrigation return flow enters at the neck of horse head. It carries a higher sediment concentration than the river.
40	4S	23E	35	R	CF16	W							7606 II	A ditch transporting irrigation tailwater enters from the right bank immediately below the small point bar. The return water is relatively clear.
41	4S	23E	35	R	CF17	W							7606 I	Waste water from canal enters the river from the right bank. It contains a higher sediment concentration. The return channel has excessive gully erosion.
42	5S	23E	3	R	CF17	W							7607 II	Irrigation return flow enters on the outside of the bend. There is a very small amount of flow.
42A	5S	23E	3		CF17	W	68	64	3.2	129	64	16	7608 III	Sampling Site: east of highway, immediately downstream from 2 farm buildings and land leveler, 12 feet from left bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
43	5S	23E	3	L	CF18	W							7608 IV	Groundwater return flow enters from under the highway from the old river channel. The return flow is relatively clear.
44	5S	23E	3	R	CF18	W							7608 I	A groundwater drainage ditch on the right bank enters the outside of the bend. The bend is partially obscured by tree shadows. The return water is relatively clear.
45	5S	23E	10	L	CF18	W							7609 III	Drainage from an oxbow area across the highway enters on the left bank. Irrigation return flows contribute to the oxbow.
46	5S	23E	10	R	CF18	W							7609 I	Irrigation return flow enters from the right bank near the farmstead. Considerable erosion is evident on the outside of the river bend downstream from the point of entry. The thermal imagery indicates a cooler inflowing water. The photograph shows a higher sediment concentration in the return water but the plume can be traced for only a short distance. Cooler, more dense water would sink.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
47	5S	23E	10	R	CF18	W							7610 I	Irrigation tailwater returns through a small group of trees. The water is relatively clear.
48	5S	23E	16	L	CF19	W							7610 I-IV	Return flow from a high water table enters from the left bank. The water is relatively clear.
49	5S	23E	16	R	CF20	W							7612 III	A small gully has been eroded on inside of the bend near several stock pens. The water observed in the gully is relatively clear at the upstream end but the turbidity increases from pool to pool downstream. The gully would be the interceptor for the stock pen drainage and this may account for the increased turbidity level. The point of inflow into the river is at the downstream tip of the sand bar and is obscured slightly by the shadows.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
50	5S	23E	16	L	CF20	W							7612 III	Groundwater return flow enters the river from a small ditch on the left bank. The ditch provides drainage for the high water table. The water is relatively clear.
51	5S	23E	16	R	CF20	W	69	64	2.5	119	62	17	7612 I	Sampling Site: 150 feet upstream from bridge east of Fromberg, 165 feet from right bank.
52	5S	23E	16	R	CF20	W							7612 I	Bluewater Creek enters the river from the right bank. It has a higher sediment concentration than the river. The plume boundary can be traced for 100 feet downstream. Some carving of the banks of Bluewater Creek can be seen in the vicinity of the irrigated fields. (See Figure 9)
52A	5S	23E	21		CF20	W	72	64	1.8	180	72	18	7612	Sampling Site on Bluewater Creek: Taken from upstream side of county road bridge, south of Fromberg, 6 feet from left bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
53	5S	23E	21	L	CF20	W							7613 II	Some ponded water in the old meander loop drains to the river in a small gully from the left bank. Erosion is occuring on the outside of the bend at this location. A new point bar is forming on the inside of the bend indicating bank erosion from the bend immediately upstream.
54	5S	23E	21	L	CF21	W							7613 IV	There is irrigation return flow entering from the left bank under the highway and railroad next to a farm road. This has a higher sediment concentration than the river and the plume boundary can be seen for at least 300 feet downstream.
55	5S	23E	29	R	CF21	W							7614 I	Flow enters from the right bank at the outside of the bend. Two sources contribute to this flow. One is a high water table area in an old meander loop. The second is a irrigation return flow from across the road. The irrigation return flow has a high sediment concentration.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
56	5S	23E	29	L	CF21	W							7615 Mid	Irrigation return flow enters the river from the left bank at the sandbar. The water is relatively clear.
57	5S	23E	29	R	CF21	W							7615 I	Irrigation return flow enters from the right bank at a slightly higher concentration than the river.
58	5S	23E	32	R	CF22	W							7616 I	There is a large irrigation return flow at a higher sediment concentration than the river entering from the right bank at the outside of a large bend. The plume can be traced downstream for about 1000 feet.
59	6S	23E	3	R	CF23	W							7618 II	An inflow with a high sediment concentration can be seen entering from the right bank adjacent to a farm house in line with a section line road. The source of this discharge can not be identified.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
60	6S	23E	3	R	CF23	W							7618 I	A creek enters the river from the right bank near a farmstead. It has approximately the same sediment concentration as the river. The mouth of the creek is about 300 feet downstream from sampling site #19.
60A	6S	23E	3	L	CF23	W	70	62	2.3	129	54	19	7618	Sampling Site: 50 feet out (right) from downstream point of brushed island.
61	6S	23E	3	L	CF23	W							7618 I	High water table drainage ditch enters from the right bank about 800 feet downstream from railroad bridge. The water is relatively clear.
62	6S	23E	3	L	CF23	W							7618 I-IV	Sand Creek enters the river from the left bank about 1000 feet upstream from railroad crossing. It has a higher sediment concentration than the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
63	6S	23E	3	R	CF23	D							7619 III	Irrigation waste water return ditch enters the river on the right bank approximately 800 feet downstream from farm.
64	6S	23E	9	L	CF24	W							7619 IV	Irrigation return flow enters the river from the left bank from the fields across the highway. The return water has a higher sediment concentration than the river.
65	6S	23E	9	L	CF24	W							7619 IV	Irrigation drainage enters the river on the left bank through the trees near a farmhouse. The water is relatively clear.
66	6S	23E	15	R	CF25	D							7621 I	A drainage ditch intersects the river from the right bank at a bend midway between two large islands. There is no flow at present.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
67	6S	23E	15	L	CF25	W							7622 I-II	Groundwater return flow from an old meander loop enters from the left bank. The water is relatively clear.
68	6S	23E	22	R	CF25	W							7623 II	Groundwater return flow from a high water table area enters on the right bank. The return water has a slightly higher sediment concentration than the river. There is very little flow here. This is about 2/3 mile below the Bridger bridge.
69	6S	23E	22	R	CF25 26	W							7623 I	Groundwater return flow enters the river from the right bank about 1000 feet downstream from Bridger Bridge. The discharge is relatively clear and small.
70	6S	23E	22	L	CF26	W							7624 I	Groundwater return flow enters the river from the left bank approximately 700 feet downstream from the Bridger Bridge. The water is relativ-ely clear.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
70A	6S	23E	22	R	CF26	W	60	61	2.3	249	53	20R	7624	Sampling Site: 100 feet upstream from bridge east of Bridger, 20 feet from right channel.
70B	6S	23E	22	L	CF26	W	60	62	2.0	124	57	20L	7624	Sampling Site: 100 feet upstream from bridge east of Bridger, 38 feet from left bank. The color of the water at the sampling sites is relatively uniform and does not indicate a difference in sediment concentration of the magnitude obtained from the samples.
71	6S	23E	22	L	CF26	W							7624 Mid	A groundwater return flow drainage ditch enters the river upstream of the sewage lagoon. The water is relatively clear.
72	6S	23E	27	L	CF26 27	W							7625 Mid	Groundwater return flow enters the river from the left bank. The water is relatively clear.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
73	6S	23E	27	L	CF27	W							7625 I	Irrigation return flow enters the river from the left bank near the farmstead below the middle bar. The return flow has a higher sediment concentration than the river.
74	6S	23E	27	R	CF27	W							7625 I	A creek located at the upstream end of a large island is carrying a higher sediment concentration than the river. The inflow can be traced for approximately 1000 feet downstream. The creek has a deeply incised meandering channel that passes through irrigated farm land.
75	6S	23E	33		CF28	W	60	60	2.5	67	53	21	7627	Sampling Site: 125 feet downstream from main highway bridge, 35 feet from right bank.
76	7S	23E	4	R	CF28	W	62	60	1.0	109	57	22	7628 II	Bridger Creek enters the river from the right bank approximately 1500 feet upstream from the highway bridge. It has a slightly higher sediment concentration. Sampling Site on Bridger Creek: 5 feet downstream from county road bridge, 5 feet from right bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
77	7S	23E	4	L	CF28	W							7628 II	Return flow from a ponded area is an old meander channel which enters the river from the left bank approximately 800 feet downstream from Bridger Creek.
78	7S	23E	8	R	CF29	W							7630 Mid	Cottonwood Creek enters from the right bank. It has a higher sediment concentration than the river. The plume is visible for about 800 feet downstream of the confluence.
79	7S	23E	8	R	CF29 30	W							7631 IV	Groundwater irrigation return flow runs past the farm and drains into river on the right bank. The inflow is relatively clear.
80	7S	23E	8	L	CF30	W							7631 IV	Two drainage ditches combine and flow under the highway and enters the river on the left bank, on the upstream side of a farmhouse. The return water has a higher sediment concentration than the river and the inflow is visible for about 600 feet downstream.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
81	7S	23E	8	R	CF30	W							7631 IV	Groundwater return from the ponded area in the old meander loop enters from the left bank. The water is relatively clear.
82	7S	23E	18	L	CF30 31	W							7633 II	Return flow enters the river from the left bank upstream of the farmstead. The water is relatively clear.
83	7S	23E	18		CF31	W	59	60	2.0	130	57	23	7633	Sampling Site: 15 feet downstream from county road bridge, 25 feet from right bank.
84	7S	23E	18	L	CF31	W							7634 II-III	Return flow enters the river from the left bank immediately upstream of bridge. This inflow is clearer than the river.
85	7S	23E	30	R	CF32	D							7636 II	Drainage patterns delineated by vegetation, enter from the right bank. They are dry at this time of year.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
86	7S	23E	30	R	CF32	W							7636 I-II	Return flow ditch enters the river from the right bank about 1300 feet downstream from Hunt Creek. The water in the bottom of the ditch is relatively clear.
87	7S	22E	25	R	CF32 33	W							7636 I	Hunt Creek is carrying a high sediment load and can be seen for at least 1200 feet downstream.
88	7S	22E	25	R	CF33	W							7638 II	Irrigation drainage goes under a road immediately downstream of a corral. The point of intersection with the river is hidden in the trees but it does not appear to have a higher sediment concentration than the river. (See Figure 5)
89	7S	22E	25		CF33	W	56	62	2.0	158	75	24	7638	Sampling Site: 1/8 mile downstream from Dry Creek, 75 feet upstream from main highway bridge, 15 feet from left bank. (See Figure 5)

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
90	7S	22E	25	L	CF33	W							7638 III	Dry Creek enters the river about 700 feet upstream of the bridge and is carrying a very high sediment load. This plume can be seen for a distance well past the bridge and around the bend (about 1700 feet). (See Figure 5)
90A													7638 IV	On left bank irrigation canal waste way approximately 500 feet upstream from diversion dam. (See Figure 5)
91	7S	22E	35	R	CF34	W							7639 I-IV	Silver Tip Creek is carrying a high sediment load which generates a plume that can be seen for about 1/2 mile downstream.
91A	8S	22E	12			W	58	60	0.25	676	295	26		Sampling Site on Silvertip Creek: 50 feet upstream from USGS gaging station, 4 feet from left bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
92	8S	22E	2	R	CF34	W							7640 II	There is irrigation return flow on the right bank coming from under the highway at a farm about 1700 feet upstream of Silver Tip Creek. This also is carrying a higher sediment concentration than the river.
93	8S	22E	3	L	CF35	D							7642 I-IV	There is a dry creek bed that enters river from under a dirt road bridge between highway bridge and diversion dam on left bank.
94	8S	22E	3	L	CF35	D							7642 I	There is a dry ditch about 800 feet upstream from the aforementioned dry creek bed.
95	8S	22E	11	L	CF35	W							7643 Mid	There are two small drainages from the left approximately 800 feet on the left bank. The contribution to the total load of the river at this flow rate would be very small.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
96	8S	22E	10	R	CF35	W	54	60	2.8	98	45	25	7643	Sampling Site: immediately upstream of main highway bridge, north of Belfry, 40 feet from right bank.
97	8S	22E	11	L	CF36	W	54	59	.45	252	100	27	7644 I-II	Bear Creek has a high sediment concentration. This plume can be discerned for nearly 1/4 mile downstream. Sampling Site on Bear Creek: immediately upstream of highway bridge, north of Belfry about 5 feet from left bank.
98	8S	22E	13	R	CF36	W							7647 I	Irrigation canal wasteway. The resulting plume in the river indicates a slightly higher turbidity than the river.
99	8S	22E	13	L	CF36	W							7648 I	Return flow from irrigation on the left bank. The inflow has a slightly higher turbidity than the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
100	8S	22E	13	L	CF36 37	W							7649 III	Irrigation return flow at the left bank with high turbidity near what appear to be bee hives, upstream of farm structures at a bend to the right.
101	8S	22E	27	R	CF38	W	53	59	2.3	84	42	28	7651	Sampling Site: 2.9 miles upstream from Belfry at main highway bridge, 30 feet from right bank.
102	8S	22E	28	R	CF38	W							7652 II	There is a gate for either letting water in or out from the irrigation channel. This is about 2200 feet upstream of the bridge.
103	8S	22E	28	L	CF38 39	W							7653 III	Wolf Creek is carrying a higher turbidity than the river but the flow is entirely the result of irrigation return flow. Wolf Creek channel is completely dry about 2000 feet from the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
104	8S	22E	34	L	CF39	W							7654 III	There is irrigation return flow coming into the left bank from under the highway at a very straight portion of the river. This is upstream of a farmhouse about 900 feet. This flow has a very high turbidity.
105	8S	22E	34	R	CF39	D							7654 II	There is a drainage ditch (dry) entering on the right bank at the peak of a bend to the left.
106	8S	22E	34	L	CF39 40	D							7654 I	A drainage ditch immediately upstream of a farm on the left bank and not contributing any flow at this time.
107	9S	22E	3	L	CF40	W							7655 I-II	Network of small irrigation return channels entering at left bank in the vicinity of the sand bar.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
108	9S	22E	3	R	CF40	D							7656 II	A complex of gullies discharging into a culvert and drainage ways on the right bank approximately 1500 feet downstream from bridge under irrigation canal. It is not contributing much flow at this time.
109	9S	22E	3	R	CF40	W							7656 II	Hallenbeck Draw enters on the right bank. It is dry but it intersects with a flowing ditch about 300 feet above the river. This ditch flows into the river about 500 feet downstream from the highway bridge. Inflow has about same sediment concentration as the river.
110	8S	22E	34		CF40	W	55	59	7.6	87	42	29	7656	Sampling Site: 3.9 miles upstream from Belfry at second main highway bridge, 15 feet from right bank.
111	9S	22E	3	R	CF40	W							7656	A creek runs parallel to highway and enters the river about 300 feet upstream of the bridge. This appears to have the same sediment concentration as the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
112	9S	22E	3	L	CF40	D							7656 I-IV	A vague pattern through the cultivated fields shows remnants of Grove Creek. No water is flowing and the channel has been obliterated by the reclamation to farmland in the flood plain.
113	9S	22E	3	L	CF40 41	W							7656 I	There is irrigation near the farm about 1/2 mile upstream from the bridge. The confluence with the river is obscured by trees but there is no indication of high sediment inflow.
114	9S	22E	18	L	CF42	D							7659 IV	A gully enters the river from the left bank opposite a feed lot operation. Gully is dry.
115	9S	22E	18	R	CF42	D							7660 III	Gully intersects river from right bank, no flow at this time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
116	9S	22E	18	L	CF42	W							7660 IV	Another gully intersects the left bank, no visable flow in gully. Seepage into the gully from irrigation can be detected.
117	9S	22E	4	R		W	56	59	2.2	74	40	30		Sampling Site: immediately upstream from county road bridge. 15 feet from right bank. This has not been located on the photograph.
118	9S	22E	18	L	CF42	W							7660 IV	Dilworth Creek enters from the left bank. Inflowing water appears to have same sediment concentration as the river.
119	9S	22E	19	R	CF43	W							7661 III	Irrigation waste water from irrigation channel enters river from right bank. The diversion point is located approximately 1 mile from county road bridge.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
120	9S	22E	19	L	CF43	W							7661 III	There is irrigation return flow entering on left bank, next to a farm. It has a higher sediment concentration than the river and can be traced approximately 1000 feet downstream.
121	9S	22E	19	L	CF43	W							7661 IV	There are irrigation return channels entering the river on the left along the straight reach of the river. No water can be detected in the channel because of the heavy vegetation.
122	9S	22E	20	L	CF43	W							7662 Mid	There are two irrigation return channels into the river from the left bank, one approximately 800 feet from bridge and the other 400 feet downstream from bridge. The downstream ditch appears to be dry. Water in upstream ditch has sediment concentration higher than the river.
123	9S	22E	20	L	CF43	W							7662 I	There is irrigation return flow 1200 feet upstream of the bridge. The flow rate appears very small and there are no indications of high sediment concentration.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
124	9S	22E	29		CF43	W	56	57	2.3	114	46	31	7663	Sampling Site: 150 feet upstream from county road bridge, 20 feet from left bank.
125	9S	22E	29	L	CF44	W D							7663 I	Irrigation return flow enters on left bank, approximately 1000 feet upstream from county road bridge. Inflowing water has slightly higher sediment concentration than the river.
126	9S	22E	29	L	CF43 44	D							7663 I-II	Two groundwater return ditches draining a high water table area enter the river from the left bank, approximately 400 feet downstream from irrigation canal siphon. No flow can be detected in these at the present time.
127	9S	22E	29		CF44	D							7663 I	Drainage patterns converge on the right side of the highway and the resulting gullies intersect the river from the right bank approximately 100 feet upstream from the siphon. The gully is dry at this time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
128	9S	22E	32	R	CF44	D							7664 II	A gully enters the river approximately 100 feet from the right bank and approximately 1700 feet downstream of the Big Sand Coulee. It is dry except from same backwater at the mouth.
129	9S	22E	32	R	CF44	W							7664 I-II	The Big Sand Coulee enters the river about 400 feet downstream from the bridge. The inflow has a higher sediment concentration than the river and it can be traced for about 700 feet downstream.
129 A	9S	22E	32		CF44	W	58	58	1.0	116	57	33	7664	Sampling Site on the Big Sand Coulee: 1/4 mile upstream from confluence with Clark's Fork at bridge near farm house, 10 feet from right bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
130	9S	22E	32		CF44	W	57	57	4.0	80	51	32	7664	Sampling Site: 60 feet downstream from county road bridge, above Big Sand Coulee, 12 feet from right bank.
131	9S	22E	32	R	CF44	W							7664 I	An irrigation return drainage ditch enters the river about 1200 feet upstream from the bridge. The return water has a higher sediment concentration than the river.
132	58N	101W	20	L	CF45	D							7666 IV	An irrigation return drainage ditch enters from the left bank approximately 3000 feet downstream from the bridge. There is some ponded water in the ditch but it does not appear to be flowing into the river at this time.
133	58N	101 W	20	R	CF46	W							7666 I	An irrigation return ditch appears to enter the river from the right bank immediately downstream from a large feed lot. The point of entry is hidden by the trees and shadows of the bank. The water in the ditch has approximately the same sediment concentration as the river. The thermal imagery indicates the ditch enters the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
134	58N	101W	20		CF46	W	58	57	2.5	124	53	34	7667	Sampling Site: Immediately downstream from county road bridge, 20 feet from left bank.
135	58N	101 W	29	R	CF46	W							7667 I	An irrigation drainage ditch enters the river just upstream of a feedlot and about 1100 feet upstream of a bridge. The sediment concentration is about the same as the river.
136	58N	101 W	32	R	CF46	D							7668 I	An irrigation drainage ditch enters from the right bank downstream of a sprinkler irrigated field. The ditch is dry at present.
137	58N	101 W	32	L	CF46	W							7668 I	A head gate structure returns some of the water diverted for irrigation from the river. The structure is located approximately 1500 feet from the point of diversion.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
138	58N	101 W	32	L	CF46	D							7668 I-IV	The main gully from the uplands enters from the left bank approximately 500 feet downstream from the irrigation diversion. A flume over the irrigation canal allows any runoff to reach the river. It is dry at this time.
139	58N	101 W	32	R	CF46 47	W							7669 Mid	An irrigation return drainage ditch enters from the right bank from the sprinkler system. The flow is very small.
140	58N	101 W	31	L	CF48	D							7670 III	A gully enters the river from the left bank. Deposits at the mouth indicate the flow from this gully contributes large sediment during runoff. The gully is dry presently.
141	57N	102 W	1	L	CF47 48	D							7671 III IV	Several drainage patterns and major gullies enter the river from the uplands on the left bank. These are dry at this time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
142	57N	102 W	1	L	CF48	W							7672 III	A small creek (Line Creek ?) enters the river near a middle bar. There is a cultivated field upstream and barren ground downstream. The inflow is clearer water than the river.
143	57N	102 W	1	L	CF48	W							7672 IV	Irrigation return flow enters the river from the left bank in a gully. Water in the gully can be seen approximately half the length of the field. Upstream from that point the gully is dry.
144	57N	102 W	1	L	CF48	W							7672 IV	Seepage from an irrigation ditch enters the river from the left bank in a small gully system The return flow has about the same sediment concentration as the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
145	57N	102 W	1	L	CF49	D							7673 I-IV	Small drainage patterns (dry) converge at the peak of a small bend to the left. This is about 1 mile upstream from Line Creek.
146	57N	102 W	1		CF49	W	58	55	2.7	80	37	35	7674	Sampling Site: Immediately downstream from bridge on paved road, 20 feet from left bank.
147	57N	102 W	12	L	CF50	D							7675 I	A gully enters the river just upstream from the fish hatchery. The gully is dry but a fan shaped deposit at the mouth indicates considerable sediment input at times.
148	57N	102 W	13	L	CF51	D							7676 I	An irrigation return ditch enters from the left bank about midway between two middle bars. The ditch is dry at present.
149	57N	102 W	13	L	CF51	W							7677 II	An irrigation return flow enters from the left bank in a gully. The return flow is relatively clear water.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
150	57N	102 W	13	L	CF51	W							7678 II	Bennett Creek enters from the left bank. It has a lower sediment concentration than the river. The thermal imagery indicates Bennett Creek is colder than the river. The inflowing water can be traced on the color infrared photo about 800 feet and on the thermal imagery for about 1500 feet. (See Figures 7 and 8)
151	57N	102 W	13	L	CF51	W							7678 II	Irrigation return flow enters the river from the left bank in a tree covered ditch upstream from Bennett Creek. There is some flow. The discharge is very small and is obscured by the vegetation near the mouth.
152	57N	102 W	13	L	CF51 52	W							7678 I	Irrigation return drainage ditch enters from the left bank near the farmstead. The discharge is very small.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
153	57N	101 W	19	L	CF52	W							7679 I	Tailwater from an irrigation channel enters just downstream of the pipe that crosses the river. The return flow has about the same sediment concentration as the river.
154	57N	101 W	19	R	CF52	D							7680 I-II	Numerous gullies intersect the river between the pipe carrying the irrigation water and the first highway bridge upstream. This is in an area where the vegetation is very sparce and there is much erosion. The gullies are dry at this time.
155	57N	101 W	30	R	CF52	D							7681 I-IV	A gully enters the river about 1100 feet below the highway brdige. The erosion pattern is deeply incised and indicates high sediment concentrations are possible from this area. The gully is dry at this time.
156	57N	101 W	30		CF52	W	66	57	2.0	98	44	36	7681	Sampling Site: 150 feet downstream from main highway bridge, 40 feet from right bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
157	57N	101 W	30	R	CF52	D							7681 I	Little Sand Coulee enters from the right bank between the two highway bridges. The alluvial fan at the mouth indicates large sediment transport during runoff occurs in this gully. The gully is dry presently.
158	56N	102 W	4	R	CF54	D							7685 I-II	Several gullies enter the river from incised erosion patterns on the right bank. These gullies were dry at the time.
159	56N	102 W	4	R	CF54	D							7686 II	Two gullies intersect the river at the upstream end of a bend. They are dry at the time.
160	56N	102 W	5	R	CF55	D							7687 II	A dry creek bed emanates from a draw on the right bank and enters at a straight reach of the river. Deposits at the confluence are evident for about 200 feet along the bank and indicate considerable sediment has been transported in this creek during the runoff. No flow was evident at this time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
161	56N	102 W	8	L	CF55 56	W							7688 II-III	Part of the irrigation channel flow is diverted back to the river about 1/2 mile downstream from the old bridge location. This has about the same sediment concentration as the river; this would be expected since the channel originated less than a mile up the river.
162	56N	102 W	8	R	CF56	D							7688 I-II	There are rainfall drainage patterns (dry) along the bend to the left just downstream of the old bridge location. Several gullies enter the river from incised erosion patterns on the right bank, downstream of the old bridge location. These were dry at the time.
163	56N	102 W	8		CF56	W	66	59	2.7	52	36	37	7688	Sampling Site: at old bridge location just downstream from Pat O'Hara Creek, 20 feet from left bank.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
164	56N	102 W	8	R	CF56	W	68	60	0.8	24	23	38	7688 I	Pat O'Hara Creek joins the river immediately upstream of the old bridge location. The gully is covered with vegetation and there is a cultivated field on the upstream side of the creek; other than that the surrounding area is barren. The color of the creek is a much lighter blue than the river, which would normally indicate a higher sediment concentration. However, there was very little flow at this time so the color is likely due to the reflection from its bed. This is further substantiated by the low turbidity measurement of 23 JTU taken on the creek. The deposits at the mouth indicate high sediment loads were carried by the creek at some time. Sampling Site on Pat O'Hara Creek: Immediately downstream from small wooden bridge, 5 feet from right bank.
165	56N	102 W	8	R	CF56	W							7689 I-II	Irrigation return flow enters from a small ditch at the diversion dam, from the right bank. The discharge is very small and the water is obscured by vegetation.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
166	56N	103 W	12	L	CF57	W							7691 III IV	A ditch intersects the river at a 45° bend to the right. This is covered by vegetation and its water appears to be al least as clear as the river. Irrigation return flow enters from the left bank. This water is relatively clear.
167	56N	103 W	12	L	CF57	D							7692 II III	Incised channel in the sand on the left bank about 1100 feet downstream of the footbridge indicates inflow to the river. Its origin cannot be determined but it is suspected that the source is irrigation return flow from adjacent fields.
168	56N	103 W	12	L	CF57	W	68	59	2.6	7	32	39	7692 II	Sampling Site: at footbridge across Clarks Fork near farm houses, 50 feet from left bank.
169	56N	103 W	13	L		W	72	59	2.7	71	33	40	7692	Sampling Site: about 1 mile downstream from river ford, 12 feet from left bank. The exact location in relation to Paint Creek has not been established.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
170	56N	103 W	13	R	CF58	W							7692 I	Paint Creek joins the river upstream of the footbridge. It has a higher sediment concentration than the river. A bar has formed immediately downstream of the mouth from sediment carried during periods of high run-off.
171	56N	103 W	14	R	CF58	D							7693 I-II	Vegetation pattern delineates irrigation return flow paths (dry) which enter the river at 3 locations upstream from Paint Creek about 1/2 mile.
172	56N	103 W	22	R	CF59	D							7695 I	A gully enters the river from the right bank. A small bar has formed at the mouth of the gully It was dry at the time.
173	56N	103 W	15	R	CF59	D							7697 I-II	Two draws (dry) drain upstream of aforementioned creek about 1700 feet. There is almost no vegetation around them except for trees and brush at the mouths. Numerous gullies enter from the upland on the right bank. All were dry at the time.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
174	56N	103 W	16	R	CF60	D							7698 I-II	Several gullies provide drainage from the sulphur colored (on color infrared photograph) deposits near the mouth of the canyon. These were dry at the time.
175	56N	103 W	16	R	CF60 61	D							7699 II III	A drainage path enters the river from the rocky hills on the right bank. It is dry at this time.
176	56N	103 W	16	R	CF61	W							7699 IV	A drainage ditch from a high water table area enters the river from the right bank. The water is relatively clear.
177	56N	103 W	7	L	CF62	W							7702 Mid	A creek enters from the left bank, from under the highway near the end of the pavement. Vegetation delineates the channel path. The water is relatively clear.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
178	56N	103 W	7	L	CF62	D							7702 IV	Two ditches (dry) located about 2300 feet and 3100 feet upstream of the pavement end enter from the left bank.
179	56N	103 W	7	L	CF62 63	W							7703 IV	Another ditch about 1200 feet upstream from the preceding site is carrying fairly clear water and there is vegetation along its banks. A creek enters the river from the left bank. The water is relatively clear.
180	56N	103 W	7	R	CF63	D							7703 I-IV	There are drainage patterns (dry) emanating from steep, rock cliffs upstream about 900 feet from the preceding site. They were dry at the time.
181	56N	104 W	13	L	CF63	W							7705 III	There is a braided creek joining the river about 1200 feet upstream from the preceding site. There is almost no vegetation along its banks. The water has a lower sediment concentration than the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
182	56N	104 W	14	L-R	CF64	D							7706 II III	There are drainage patterns, draws and gullies (all dry) incised into the canyon walls for about the next 1 1/2 miles along both banks.
183	56N	104 N	26	L	CF66	W							7707 IV	Very heavy vegetation follows a creek and obscures the view such that is is even difficult to determine whether it is flowing or not. There appears to be a slight trickle of water at the mouth but its sediment concentration cannot be compared to the river's from the photo.
184	56N	104 W	35	L-R	CF66	D							7708 II III	There are many drainage patterns (dry) for about the next 1/2 mile upstream of the preceding site.
185	56N	104 W	33	R	CF67	W							7717 I-II	Dead Indian Creek enters from the right bank. The cascading water makes it difficult to distinguish its color. However, it appears to be nearly the same sediment concentration as the river.

TABLE 6 - Location and Discussion of Tributaries to the Clarks Fork Yellowstone River and Accompanying Sample Sites, con't.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
186	56N	104 W	33	R	CF67	W							7717 I	Sunshine Creek enters the river approximately 1200 feet upstream from Dead Indian Creek from the right bank. The cascading water makes it difficult to distinguish its color.
187	56N	104 W	29	L-R	CF68	?							7719	There is heavy vegetation in the draws on both sides of the river. No water is seen flowing into the river at this time.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R1	4S	23E	1	R	RC1	W							7776 IV	Groundwater drainage ditch enters Rock Creek about 900 feet above the confluence with the Clarks Fork. The sediment concentration appears to be the same as Rock Creek. There is some algae on a section of ponded water in the ditch.
R2	4S	23E	2		RC2	W	73	70	2.3	7	11	10	7774	Sampling Site: 100 feet downstream from highway bridge, 25 feet from left bank.
R3	4S	23E	3	L	RC3	W							7774 II III	Water originally diverted for irrigation is drained back about 2000 feet upstream of the highway bridge. The flow is a mere trickle with approximately the same sediment concentration as Rock Creek.
R4	4S	23E	9	R	RC4	W							7772 IV	Irrigation return ditch enters from right bank. It originates on the irrigated bench above the floodplain. It has a slightly higher sediment concentration than Rock Creek.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R5	4S	22E	13	L	RC6	W							7767 I	Groundwater return ditch follows the old river channel and enters the river about 900 feet upstream of farm buildings. The sediment concentration is about the same as Rock Creek. The thermal imagery indicates the temperature to be slightly cooler than Rock Creek.
R6	4S	22E	21	L	RC7	W							7766 I-II	Irrigation return flows in through a straight line ditch about 3300 feet below the Joliet Bridge. This is relatively clear water.
R7	4S	22E	21	L	RC8	W							7764 II	A straight line irrigation return ditch enters Rock Creek from the left bank just upstream of Joilet. The water is relatively clear. The temperature, however, is slightly less than Rock Creeks.
R8	4S	22E	32	L	RC8-9	W							7762 I	Flow that is diverted between the railroad and highway bridge reenters about 2300 feet downstream.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R9	4S	22E	22		RC9	W	74	68	1.5	11	10	5	7762 I	Sampling Site: 40 feet upstream from railroad bridge, 40 feet from right bank.
R10	4S	22E	32	L	RC9	W							7762 II	Return flow from a main irrigation channel enters 500 feet upstream of the railroad bridge. This is relatively clear water.
R11	4S	22E	20	R	RC10	W							7759 I	Drainage from a highwater table area in the flood plain immediately below an irrigation diversion structure. There is irrigation drainage entering this are, some of which has a high sediment concentration. The ponds in the area act as settling basins so the sediment never reaches the river.
R12	4S	22E	20	L	RC10	D							7759 I	There is a vegetation pattern on the left bank, which indicates a gully joins Rock Creek just downstream of the farm house. It is dry.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R13	4S	22E	20	L	RC10	D								A straight line irrigation return ditch enters Rock Creek on the left bank. It is dry.
R14	4S	21E	24		RC12	W	75	68	1.8	11	9	6	7755	Sampling Site: Immediately downstream from Red Lodge Creek-Rock Creek Confluence, 50 feet from left bank.
R15	4S	21E	21	R	RC12	W							7755 I	Rock Creek-Red Lodge Creek Confluence, the rivers appear to have about the same sediment concentration.
R16	4S	21E	25		RC13	W	75	68	2.5	77	5	7	7753 IV	Sampling Site: on Rock Creek, 75 feet upstream from county road bridge. West on Boyd, 10 feet from left bank.
R17	4S	21E	24	R	RC13	W							7753 II	A small creek enters from the right bank. There is some water in the creek but it becomes dry before it reaches the river.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R18	4S	21E	26	L	RC14	W							7753 II	Grove Creek enters a cutoff from the left bank. It has a higher sediment concentration than Red Lodge Creek.
R19	4S	21E	35	R	RC14	D							7752 III	An irrigation return joins the river immediately downstream of a bridge at a sharp bend to the left. It is dry at this time.
R20	4S	21E	35		RC14	W	72	70	2.5	.15	11	8	7752	Sampling Site: 5 feet upstream from bridge on side road, 10 feet from left bank.
R21	4S	21E	34	L	RC14 15	D							7750 I-II	Several gullies intersect the river from the left bank. They drain primarily barren, plowed fields
R22	4S	21E	34	R	RC15	D							7748 IV	Several drainage patterns, on the uplands of the right bank, converge and cross the road and enter the river. They are dry at this time.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R23	4S	21E	34	L	RC15 16	D							7748 I-II	Three gullies enter the river, upstream of a farmhouse, from the drainage patterns in the uplands on the left bank. They are dry at this time.
R24	4S	21E	34	L	RC16	D							7746 I-II	Two dry gullies converge and enter the river between two cultivated fields at a cut-off but flowing oxbow. These draws contrast well with the surrounding area on the thermal imagery. They are cooler than both the river and the surrounding area except for the cultivated fields near the river.
R25	4S	21E	34	R	RC16	D							7746 I-II	Two dry gullies converge on the right bank and enter the river.
R26	4S	21E	34	L	RC16	W							7745 I-II	A gully draining the highland of the left bank enters Red Lodge Creek approximately 1200 feet downstream from a farmstead.

TABLE 7 - Location and Discussion of Tributaries to Rock Creek and Red Lodge Creek and Accompanying Sample Sites.

Location No.	Township	Range	Section	Bank	Thermal Imagery Location	Wet or Dry	Air Temp. (°F)	Water Temp (°F)	Water Depth (Ft.)	Suspended Solids (ppm)	Turbidity (JTU)	Sample Site No.	Photo No. Quadrant No.	Description
R27	4S	21E	30	R	RC17	W							7743 I	Cottonwood Creek enters Red Lodge Creek about one mile below Cooney Dam. The sediment concentration is higher than Red Lodge Creek's. Cottonwood is slightly cooler than Red Lodge Creek. There are some irrigation drainage patterns that join Cottonwood Creek but nothing in the photograph is flowing.
R28	4S	21E	30	L	RC17	D							7743 I-II	Small gully enters the river about 3000 feet below the dam from the left bank. It is dry.
R29	4S	20E	36		RC18	W	72	66	2.2	4	7	9	7742	Sampling Site: below Cooney Dam, 50 feet upstream from USGS gaging station, 10 feet from right bank.

CONCLUSIONS

Inflows from tributaries, ditches, and gullies to the Clarks Fork Yellowstone River have been identified. Table 8 summarizes the contributing sources, real and potential, of sediment to the Clarks Fork Yellowstone River. Thirty seven (37) inflows to the Clarks Fork Yellowstone River and four (4) inflows to Rock Creek - Red Lodge Creek have a higher turbidity than the receiving water at their respective points of entry. Sixteen (16) inflows to the Clarks Fork Yellowstone River and four (4) inflows to Rock Creek - Red Lodge Creek have approximately the same turbidity. Forty two (42) inflows to the Clarks Fork Yellowstone River and three (3) inflows to Rock Creek - Red Lodge Creek have lower turbidity. Forty six (46) dry sites are tabulated as entering the Clarks Fork and nine (9) are entering, Rock Creek - Red Lodge Creek. More sites are represented than the actual number itemized since several drainage patterns may be included in a single dry site description.

All streams transport sediment to some degree (either as bed load, suspended load, or wash load) based upon the type of areas they drain, the stream velocities, and bed and bank materials. During the spring run-off, higher sediment concentrations are normally encountered. As the run-off decreases, the sediment concentration decreases until a minimum generally occurs sometime during the winter months. Thus the main stream reflects the sediment input from tributaries plus the amount of sediment entrained by its own flowing water.

The tributary flows into the Clarks Fork Yellowstone River, Rock Creek and Red Lodge Creek derive their sediment from numerous sources. Tributaries commonly pass through relatively barren land supporting only sage brush, through irrigated crop lands and pasture lands, through feed lots, and through small towns. In areas where small catchments exist on the side slopes of the canyon, the exact catchment area can be delineated and sediment sources readily identified. Tables 5, 6, and 7 identify the inflowing sources of sediment and describe some of the catchment areas which drain into the tributaries of the Clarks Fork Yellowstone River. However, since most photographs cover only the portion of the drainage basin adjacent to the river a complete description is not possible for each drainage area. It can be assumed that the adjacent fields contribute some sediment and in certain cases a change in the color of the water as it passes through a given field or the location of water in the stream or gully bed is a clue to the identification of the contributing source at the time of the photographs.

In general the following observations held for most cases. Groundwater return flow has a lower turbidity than the river. In one case the groundwater return flow traveled a sufficient distance through erodible material to entrain some suspended sediment. (See location number 68). Irrigation return flows had sediment concentrations equal to or greater than the river. Red Lodge Creek and Rock Creek were relatively clear water streams. This is to be expected since Red Lodge Creek derives its water from the discharge from Cooney Reservoir. Several smaller creeks such as Bennett Creek derive their water from sources in the Absaroka Range east of Yellowstone Park and are relatively clear and cold.

TABLE 8 - Summary of Inflows with Relative Turbidity Classifications

Location Number	Higher * Turbidity Than The River	Approximately * The Same Turbidity As The River	Lower * Turbidity Than The River	Name Of Tributary
3		X		
4			X	
5			X	
6			X	
7			X	
11		X		
12		X		Farewell Creek
14		X		Cottonwood Creek
15			X	
17			X	
19			X	
22			X	Rock Creek
23			X	
26			X	
27		X		
28			X	
29			X	
30	X			Five Mile Creek
31			X	
32			X	
35			X	
37	X			Elbow Creek
38	X			
39	X			
40			X	
41	X			
43			X	
44			X	
46	X			
47			X	
48			X	
49	X			
50			X	
52	X			Bluewater Creek
54	X			
55	X			
56			X	
57	X			
58	X			
59	X			
60		X		
61			X	
62	X			Sand Creek

TABLE 8 - Summary of Inflows with Relative Turbidity Classifications, con't.

Location Number	Higher * Turbidity Than The River	Approximately * The Same Turbidity As The River	Lower * Turbidity Than The River	Name Of Tributary
64	X			
65			X	
67			X	
68	X			
69			X	
70			X	
71			X	
72			X	
73	X			
74	X			
76	X			Bridger Creek
78	X			Cottonwood Creek
79			X	
80	X			
81			X	
82			X	
84			X	
86			X	
87	X			Hunt Creek
88		X		
90	X			Dry Creek
91	X			Silver Tip Creek
92	X			
97	X			Bear Creek
98	X			
99	X			
100	X			
103	X			Wolf Creek
104	X			
109		X		
111		X		
118		X		
120	X			
122	X			
125	X			
129	X			Big Sand Coulee
131	X			
133		X		
135		X		
142			X	Line Creek
144		X		
149			X	
150			X	Bennett Creek

TABLE 8 - Summary of Inflows with Relative Turbidity Classifications, con't.

Location Number	Higher * Turbidity Than The River	Approximately * The Same Turbidity As The River	Lower * Turbidity Than The River	Name Of Tributary
153		X		
161		X		
166			X	
170	X			Paint Creek
176			X	
177			X	
179			X	
181			X	
185		X		Dead Indian Creek
R1		X		
R3		X		
R4	X			
R5		X		
R6			X	
R7			X	
R10			X	
R11	X			
R15		X		Rock Creek-Red Lodge Creek Confluence.
R18	X			Grove Creek
R27	X			Cottonwood Creek
Total on Clarks Fork	37	16	42	95
Total on Rock Creek	4	4	3	11
Total	41	20	45	106

* Turbidity levels are based upon color differences of the water in the vicinity of the confluence of the tributary and the river. The tabulated tribtaries include only those with water visible in them.

Results of this study indicate that aerial color infrared photography and thermal infrared imagery are practical tools for locating and identifying existing and potential inflows of sediment laden water to a river system. Data can be obtained rapidly and accurately.

Color infrared photography effectively detects small changes in low concentrations of suspended particles in water and enhances the change by a color difference. Interpretation of the color infrared photography provides a means of qualitatively assessing the suspended material concentration of the river system. An interpreter can evaluate the ground truth information more accurately and can locate ground sampling sites that are representative of the phenomenon of interest. Field survey work can be performed with greater efficiency and at less cost because of prior knowledge about drainage locations, terrain and accessibility.

Thermal infrared imagery provides an indication of temperature differences of the river and tributaries. In this case, tributaries entering at approximately the same or at colder temperatures were observed. Tributaries entering at a higher temperature than the river were not detected.

Each of the above two systems provide information relative to the river system. Color infrared photography is best for identifying sediment concentration differences. Thermal infrared imagery provides an indication of the relative temperature of the scene. Together they provide a unique, quasi-synoptic view of the sediment transport process in a river system.

APPENDIX

B

HOUSE RESOLUTION NO. 24

INTRODUCED BY DARROW, TOWE, FAGG, COX, FORESTER, GLENNEN, NELSTEAD, NORMAN, BRADLEY, McKITTRICK, STAIGMILLER, QUILICI, LYNCH, HARPER, LUNDGREN, AINSWORTH, J. MURPHY, McNAMER, JOHNSTON, MARBUT, SNORTLAND, BURNETT, ROBBINS, YARDLEY, KELLER, FLEMING, LIEN, SHELDEN, PARRISH, JACKSON, WOLF, CAMPBELL, ANDERSON, LAAS, KENDALL, WARFIELD, DEVINE, ZIMMER AND SCHOONOVER

A RESOLUTION OF THE HOUSE OF REPRESENTATIVES OF THE FORTY-SECOND LEGISLATIVE ASSEMBLY OF THE STATE OF MONTANA DIRECTING THAT THE BOARD OF HEALTH, THE FISH AND GAME DEPARTMENT, THE SOIL CONSERVATION SERVICE AND THE BEARTOOTH RESOURCE CONSERVATION DISTRICT STUDY POLLUTION IN CLARKS FORK OF YELLOWSTONE RIVER CAUSED BY CURRENT WATER USE PRACTICES.

IN THE HOUSE

March 2, 1971	Read first time and referred to Committee on Environment and Resources.
March 3, 1971	Committee recommends bill be adopted. Report adopted and referred to Bills Committee for enrolling.
	Reported correctly enrolled.

A RESOLUTION OF THE HOUSE OF REPRESENTATIVES OF THE FORTY-SECOND LEGISLATIVE ASSEMBLY OF THE STATE OF MONTANA DIRECTING THAT THE BOARD OF HEALTH, THE FISH AND GAME DEPARTMENT, THE SOIL CONSERVATION SERVICE AND THE BEARTOOTH RESOURCE CONSERVATION DISTRICT STUDY POLLUTION IN CLARKS FORK OF YELLOWSTONE RIVER CAUSED BY CURRENT WATER USE PRACTICES.

BE IT RESOLVED BY THE HOUSE OF REPRESENTATIVES OF THE STATE OF MONTANA:

WHEREAS, the Clarks Fork of the Yellowstone River is polluted with silt generally from the Montana-Wyoming state line to its confluence with the Yellowstone River near Laurel, and

WHEREAS, the silt pollution has destroyed much of the potential of the river for trout fishing and other recreation, and

WHEREAS, the silt pollution in the river represents a loss of topsoil to the agriculturist, the base on which a farm or ranch sustains itself on a long-term basis, and

WHEREAS, the silt pollution in the Clarks Fork has a detrimental effect on the public water supply to the downstream users often requiring costly treatment before the water can be used for drinking purposes.

NOW, THEREFORE, BE IT RESOLVED BY THE HOUSE OF REPRESENTATIVES OF THE STATE OF MONTANA:

That the Soil Conservation Service, the State Soil Conservation Committee, the Montana Water Resources

Board, the Fish and Game Department, and the State Board of Health in cooperation with the Beartooth Resource Conservation District determine where the silt pollution is coming from in the drainage.

BE IT FURTHER RESOLVED, that a report be prepared for the 1973 Legislature supervised by the Council on Natural Resources and Development stating the extent of the problem and suggesting methods for controlling the sources of erosion resulting in pollution.

BE IT FURTHER RESOLVED, that a copy of this resolution be sent by the chief clerk of the House of Representatives of the state of Montana to the Director of the Soil Conservation Service, the State Soil Conservation Committee, the Director of the Montana Water Resources Board, the Director of the Fish and Game Department, the Director of the State Board of Health, the Director of the Council on Natural Resources and Development, and the Chairman of the Beartooth Resource Conservation District.

Speaker of the House

I certify that the within Resolution was adopted March 3, 1971 by the Montana House of Representatives.

Chief clerk